View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Online Research Database In Technology

Technical University of Denmark

Electric Vehicles and the Customers

Report WP 1.3 draft

Christensen, Linda

Publication date:
2011

Link back to DTU Orbit

Citation (APA):
Christensen, L. (2011). Electric Vehicles and the Customers: Report WP 1.3 draft.

DTU Library
Technical Information Center of Denmark

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

ELECTRIC VEHICLES IN A DISTRIBUTED AND INTEGRATED MARKET USING SUSTAINABLE ENERGY AND OPEN NETWORKS

REPORT WP 1.3

ELECTRIC VEHICLES AND THE CUSTOMERS

Type:	Report
Identifier:	Rep1.3
Classification:	Draft
Version:	0.1
Access	Consortium
Editor:	Linda Christensen
Date:	07/10/2011

***Funding**: Joint by DTU Transport and Danish Government (ForskEL programme, project 081216, 500,000 DKK public financing).*

© Copyright EDISON Consortium. 2009. All Rights Reserved

Members of the EDISON Consortium

The Danish Energy Association	DEA
DTU Elektro	DTU
Risø DTU	Risø
DTU Transport	DTU
IBM Danmark A/S	IBM
Siemens	Siemens
Østkraft Net A/S	Østkraft
DONG Energy Power A/S	DONG
EURISCO ApS	EURISCO

List of Contributors

Linda Christensen, DTU Transport	Task leader

List of Reviewers

Jan Rasmussen, DE	WP1 Leader
Ole Kveiborg, DTU Transport	

© Copyright EDISON Consortium. 2009. All Rights Reserved

INDEX

© Copyright EDISON Consortium. 2009. All Rights Reserved

© Copyright EDISON Consortium. 2009. All Rights Reserved

0 SUMMARY

This report is analysing the potential travel behaviour of electric vehicles (EVs) and the need for charging infrastructure which can be derived from the behaviour.

0.1 DATA FOR THE ANALYSES

Data about the travel behaviour of the existing cars is used to simulate the potential travels of EVs. It is assumed that the driving pattern for EVs is the same as by the conventional cars.

Two different datasets are used, data from GPS loggers which have been installed in 350 cars for between 2 weeks and several month in 2002-03 (AKTA data) and the National Travel Survey data called 'Transportvaneundersøgelsen' (TU) in Danish. The AKTA dataset is illustrating the behaviour seen over a long period highlighting the changed need for charging from day to day. The data only represent one-car households in the Copenhagen area. The TU data are representative for the whole population and includes many details about the travels. However they only reports travel patterns during one day and a special treatment of the data has been necessary to be able to analyse the travel behaviour of cars and not only of the individuals who are interviewed in the survey.

0.2 TRAVEL BEHAVIOUR OF EVS AND THE NEED FOR DAILY CHARGING

The most important difference between EVs and conventional cars is that the EV has to be charged at home every night instead of being fuelled at a fuel station for every 500 km e.g. At days when the car is driving longer distances it also has to be charged outside home in the running of the day. More than half of the need for charging outside home can be overcome when the driver is participating in different activities during the day. A few percent of the cars need to be charged along a tour because it is longer than the driving range of the car.

The share of the EV car park that needs to charge outside home depends on the travel range of the cars and of the number of family members sharing the car or cars. The normal assumption in the public is that a two car family can easier have an EV than a one car family because the second car does not need to be charged as much as the only car of a family. However, the analyses show that a two car family at least in average has to charge both their cars quite as often outside home as a one car family with two or more adults sharing the car. Only singles need to charge less outside home.

Of the cars with a 150 km travel range belonging to families with two or more drivers only a little less than 10 % of the cars driving at the actual day will need to charge outside home. If the travel range in practice thanks to higher speed than 80 km/hour or need for heating is only 120 km around 15 % of the cars driving at the actual day will need to charge outside home. For singles it is only 11 %. If the travel range in practise is only 80 km 33 % of the driving cars need to be charged outside home (29 % for singles).

The analyses of the AKTA data show that it is not some families who need to charge often and others who will charge little outside home. Seen over a two week period 82 % of the one car families with two drivers will need to charge outside home one or more times if the travel range is 120 km in average. If the travel range is only 80 km 95 % will need to charge outside home at least once in a fortnight.

To conclude, if the EVs should get a market share more than next to nothing in Denmark where 70 % of all families owning a car only has one car it is absolutely necessary to establish a charging infrastructure in public and semi public areas.

© Copyright EDISON Consortium. 2009. All Rights Reserved

0.3 THE NEED FOR FAST CHARGING

The need for fast charging at a long trip is much less. If the travel range is 120 km only 4 % of the cars will need to fast charge during a day and if it is 150 km it is only 2 %. But again seen over a longer period a much higher share will need to fast charge. Along a month only a little more than a third of the one car families can do without fast charging if the travel range is 120 km. And if it is only 80 km a little more than 50 % will need to fast charge during a month. Very often those who need to fast charge at the actual day will need to charge at least twice during the day – once at the outbound and once at the homebound trip - at least.

10 % will need to fast charge in more than one day and 5 % in more than two days during a month for a 120 km travel range. If the driver is driving fast at the motorway the travel range can easily be reduced to 80 km. For these cars/drivers 15 % will need to fast charge more than two days a month. Families who need to fast charge more than 1-2 days per month are not assumed to be potential EV customers.

To conclude, with an acceptable fast charging infrastructure at least 85 % of the one car families can be potential EV customers. What the analysis also shows is that only 4-9 % of the driving cars will need to fast charge at an actual day. The number of customers at the fast charging facilities will therefore be very little resulting in a very low feasibility of fast charging or battery swapping facilities.

0.4 DEMAND FOR CHARGING POLE INFRASTRUCTURE

Based on the travel pattern with information about the geography of destinations and the activities where drivers have pauses the need for charging pole infrastructure is analysed. The electric effect of a charging pole or an electric socket is for the calculations assumed to depend on the type of activity. At home and at working places it is assumed that there will be access to a charging facility with 1 phase 16 Amps current. It is assumed that everybody having purchased an EV will have access to such a charging facility at work. At other activities it is only assumed that the EV will have access to a normal socket with 10 Amps, and at still other activities they are assumed not to be able to charge (e.g. in the forest and at the beach). Last but not least it is assumed that they will have access to a charging pole with higher effect when they go shopping or to activities in the city centres.

If the EV has a 120 km travel range only 10 % will need to charge at other times than at night. Of these 4 percent poins will not be able to cover the need for charging during periods of pauses, typically because they are driving too far, they need to fast charge. 6 % are thus able to do with charging at their activities during the day. If the above assumptions are fulfilled the analyses shows that 1.4 % can do with charging at home during daytime and 2.4 % at work. The last 2.3 % will share charging nearly equally between shopping centres and city centres, visiting friends and relatives, and other activities. The demand for charging facilities is therefore largest at work. The analyses show furthermore that fulfilment of charging needs at work is only little less if the current is only 10 Amp. This means that the need for charging at other activities is rather independent of how soon a 16 Amps infrastructure is established at workplaces.

The possibility to fulfil the need for charging at shopping centres is rather small even when a higher voltage charging infrastructure is taken into account. Two different types of charging poles are analysed, a 3 phase 16 Amp installation, and a 50 kW DC fast charger which can charge an empty battery in 20 minutes. However it can only charge the battery to 80 % of the full battery level. With a 3 phase 16 Amp installation 0.7 % of the EVs with a 120 km travel range will get enough electricity at these charging poles. However, the analysis also shows that 17 % of these will not get their charging needs fulfilled with the high effective charging installation instead of the 3 phase. Therefore the 3 phase charger will be the absolute most attractive

© Copyright EDISON Consortium. 2009. All Rights Reserved

solution - also because it is much cheaper than the high effect charger. This is a problem because at the moment the modern EVs have not chargers installed in the car which enables them to charge with 3 phases. This problem is not expected to be solved until 2017.

The very little share of EVs which can be fully charged at their daily activities also has the effect that the need for charging facilities at public areas is very modest. If all families with a car have one EV only 3 % of the cars parking in the city centre will need to charge and 2 % at other kind of shopping. If the cars only have a practical travel range of 80 km these figures will go up to 10 - 11 %. At work and study places and for business the need will be 10 % of the cars parked if they have a 120 km travel range and 30 % if the travel range is low. This means that especially at public area the need for charging infrastructure will be very little in the first many years. What is necessary is that it is available.

The real need for charging poles is for those who live in city centres and at other dense city areas who are not having access to private or semi private areas where charging facilities for night charging can be established. The analysis shows that around 8,000 EVs will need access to charging poles in the streets in these city areas if the overall EV stock is 100,000. If each pole can serve 2 EVs 4,000 poles is needed in the bigger Danish cities. Half of these are needed in central Copenhagen and a third in the 3 biggest cities. These charging poles can be reused in daytime when the EV owners leave for job and other activities. Only half as many EVs will come in for charging during the day. The only time when the capacity of the poles might be exceeded is in the evenings in the city centres where guests come to the restaurants, entertainments and to visit friends.

On top of the 4,000 charging poles in the dense areas it is estimated that 1,000 extra poles are needed in small towns and in bigger shopping areas in the suburbs of the cities. In this figure is also included the need in the big shopping centres and the extra need in some city centres. To conclude if the EV stock is 100,000 the need for charging poles in public areas will be around 5,000. And each time the stock is increased by 100,000 4,500-5,000 extra poles are needed.

0.5 FEASIBILITY OF CHARGING POLE INFRASTRUCTURE

It is analysed if the users will be able to pay enough for financing this infrastructure. It is shown that it will be possible if the EVs which need home charging pays a monthly fee at the same level as the price for establishing intelligent charging facilities in carports etc. and if the guests during the day pay an extra fee on top of the price for the electricity. The price could be a 60 kr monthly subscription for the 10 % most intensive users and 20 kr per visit for the rest (8.5 Eur / 3 EUR). What is not financed in these calculations is the first establishing period when the infrastructure needs to be in place to get the customer to come. But this will be rather little as the largest share of the charging poles will have to follow the purchase of the EVs in the dense city areas.

A similar analysis of the feasibility of fast charging facilities is not a part of the Edison project.

© Copyright EDISON Consortium. 2009. All Rights Reserved

1 INTRODUCTION

The former Danish government has decided that 30 % of the energy consumption in 2020 should be based on renewable energy, and the new government from October 3. has stated that 50 % of all electricity production in 2020 should be based on wind. The use of renewable energy as wind and wave power, solar cells etc. is more complicated than conventional energy production because production is fluctuating over the hour, day, week and month. It is therefore necessary to be able to store the energy from high production periods to low production periods and to smoothen out the daily fluctuation. For this purpose batteries of electric vehicles (EVs) might be one of the good solutions. At the same time as transport is getting electrified and based on renewable energy it will also be more energy efficient because EVs are more energy efficient than conventional cars. Electric vehicles are therefore expected to get a main role in the reduction of CO_2 from the transport sector.

One of the most important preconditions for the EV to be a success is that it is able to fulfil the travel behaviour demand of the customers. A conventional car is typically fuelled at a filling station after 500-600 km, and drivers are used to do that. This is not the case with EVs. Their driving range for the new cars is much shorter than conventional cars, typically 150-160 km according to official driving test cycle. However, in real life conditions this can vary from 50 to 200 km depending on e.g. speed and outdoor temperature. Drivers therefore need to charge more often than they need to fuel. On the other hand for many people it will be easy to charge at home by plugging in to a normal electric pole in the carport or at the parking lot at their block of flats. But is it enough to have charging facilities at home when the practical driving range is only 50-120 km? And if not, how many charging facilities are needed and where should they be located? Especially for long distance travelling a driving range of 50-150 km is too short so the EV will need to be charged on the tour.

This report is analysing the travel behaviour of Danish drivers and is addressing the demand for charging infrastructure outside home.

In chapter 2 the technological background of the EVs and of the charging infrastructure is discussed. The foundation for the analyses in the following chapters is also decided in chapter 2.

In chapter 3 the data used for the analyses is outlined and the needed data modification and modelling is described.

In chapter 4 the travel behaviour is discussed related to the travel range. The need for charging outside home is identified. The demand is divided into two types, the low energy need which can be facilitated by charging poles at which the EV can charge for longer time spans, and the fast charging needs when the driver is on a tour and need to get on as fast as possible.

In Chapter 5 is analysed the demand for normal charging facilities outside home. It is identified at which kind of activities and in which parts of the city the drivers need to charge and how many need to charge at the different activities and city areas. From these analyses the need for charging poles at different places can be identified. In this chapter is also analysed the need for charging in the streets at night of EV owners who lives in areas without private parking facilities. And last but not least the feasibility of the charging pole infrastructure is discussed.

In chapter 6 the need for fast charging or battery swapping is analysed. A model for optimising location of fast charging stations has been developed. By using the model it is analysed how many long distance travellers are served depending on how widespread the network is.

© Copyright EDISON Consortium. 2009. All Rights Reserved

2 TRAVEL RANGE AND CHARGING FACILITIES

The need for charging of an EV depends both on the travel behaviour of the car owners and on the performance of the EV. When the EVs need to be charged outside home the technology of the infrastructure is furthermore crucial for the need. In this chapter this technological precondition for the further analyses is settled.

2.1 TRAVEL RANGE OF A MODERN EV

The technology of EVs on the market and on its way into the market is varying substantially. In the 1980'es EVs were developed as the first alternative to the combustion engine cars. The battery was the lead acid battery the only known battery type in those days. It was very heavy with a low energy storage capacity per kilo with limited travel range as result, typically 50 kilometres. The cars were two seated and the acceleration was due to the weight and the low efficiency of the engine very slow. Later on nickel cadmium and nickel metal hybrid batteries has been developed resulting in lower weight and thereby longer travel ranges.

After 2005 battery technology has improved substantially with the Lithium-Ion battery as the most promising for the new generation of EVs. The interest of cars based on renewal energy consumption has in the same time increased so the market for EVs is now more ready if the performance and the price is getting right. A new generation of EVs produced by smaller alternative companies to the big automotive industry was started up in 2008-2009 with the two seated Norwegian Think and the American sports car Tesla Roaster as the most renowned. Some of the big automotive companies have rebuilt some of their combustion engine makes with 4 seats to an EV, the Citroën C1 for instance. But until 2011 the market has waited for the traditional family car as an EV.

From the beginning of 2011 Peugeot, Citroën, and Mitsubishi have introduced their small 4 seats, 5 door EVs produced for the Danish Market. Renault and Nissan have in 2010 started up in United States with a middle size family car (Fluence Z.E. and Leaf) which are expected in Denmark in the fall 2011. All these new EVs have Li-ion batteries. Furthermore Renault and Peugeot have modernised their small electric vans with among others Li-Ion battery.

All these cars in the new EV generation, including Think and Tesla Roadster, are quick accelerating and are having a top speed comparable with the same make with combustion engine. Opposite to some Chinese and Indian makes also at the market they are crash tested and therefore fully accepted as passenger cars in EU. So the driving performance is at level with modern cars. The only difference is the travel range on a fully charged battery.

The travel range of some of the new EVs tested with the European driving cycle is shown in **Table 2-1** together with other information about the performance. Except for Tesla Roadster the range is less than 200 km with the majority around 150 km. The battery capacity is 16 kWh for the small EVs and up to 24 kW for the medium size EVs and the van.

Much research capacity is in these years invested in developing the battery technology with new materials resulting in higher efficiency (effect per weight) which can lead to longer travel range. On the other hand the battery price is at a very high level, a 20-24 kWh battery costs at the moment 75,000 kr (10,000 EUR) which is expected to decrease to around 10,000 kr (1,500 EUR) over some years dependent on the market development (Foosnæss, 2011a and b). For the mainstream automotive industry, the objective for the first years will be to get the price of batteries down parallel with an effort to get mass consumption and production started up, especially for Renault as the most ambitious concern (Foosnæss, 2011a and b).

At this background it should be expected that the level of the battery capacity will not exceed the actual level for the new EVs for the first several years. The report Foosnæs (2010) recommends the Edison project to use 24 kWh for network analyses for

© Copyright EDISON Consortium. 2009. All Rights Reserved

the first 10 year and 40 kWh for the following period. It might be obvious to expect the small EVs to stick to the even smaller battery capacity because for this market segment the price is even more essential.

Table 2-1 Technical characteristics of some new EVs on the Danish Market 2011. All references are from 2011.

Fabric	Mitsubishi	Peugeot	Citroën	Nissan	Renault	Renault	Peugeot	Tesla
Make	iMiEV	iOn	C-Zero	Leaf	Fluence Z.E.	Kangoo	Partner Van	Roadster
Type:	4 seats	4 seats	4 seats	5 seats	5 seats	2 seats	2 seats	2 seat sport
Top speed:	130 km/t	130 km/t	130 km/t	145 km/t	135 km/t	130 km/t	112 km/t	200 km/t
Travel range:	150km	144 km	150km	175 km	160/185 km[1]	170 km	120km	400 km
Capacity of Battery:	16 kWh	16 kWh	16 kWh	24 kWh	24 kWh	24 kWh	23 kWh	~ 60 kWh[2]
Max engine effect:	47 kW	47 kW	47 kW	80 kW	70 kW	44 kW	42 kW	215 kW
Reference	ChoosEV	ChoosEV	ChoosEV	Nissan	Better Place / Renault	Renault	ChoosEV	Tesla

[1] Both figures are mentioned at the home page of Better Place. [2] Calculated from information about charging times

However one thing is the battery capacity another is the travel range. Most of the EVs are tested according to the European test cycle which is constructed to take into consideration an average combination of urban and rural driving. But EVs has a rather high energy efficiency in urban areas compared to the combustion engine, which is performing very badly in city streets with many traffic signals and congestion. However, the efficiency of the EV is very sensitive to high speeds which are typical on the motorways. This means that the travel range should be expected to be trusted for cars driving in cities and in rural areas with speeds up to 80 km/h. If the speed is 90 km/h the consumption is increasing 25 % and the travel range is reduced by 20 %. If the speed is 110 km the consumption is increasing 100 % and the travel range is halved related to the official range (ChoosEV, 2011 or Tesla, 2011). If the speed is increased further the consumption increases exponentially.

Another problem is the need for heating of the cabin in winter periods which is highly relevant in the Nordic countries. The combustion engine has a low energy efficiency which results in huge amounts of surplus heat which is easily used in the heating system. This is however not the case with the electric engine so energy for heating has to be entered in some way. The EVs actually on the market takes the heating from the battery and they are not constructed to save heating energy. Therefore the travel range is said to be reduced to the half in cold winter days. But this information is not documented by measurements at the moment. Think City has a 4 kW electric heather (Think, 2011). With full use it has used 25 % of the battery capacity after 1 hour. Furthermore the energy efficiency of a Li-ion battery is reduced 10-15 % when the temperature is less than – 5 degrees.

The next generation of EVs constructed as EVs from the bottom might eventually take into account the need for heating and energy saving from the cabin. It will be especially relevant if the Nordic countries and the north-eastern American states become relevant markets for EVs. As northern Japan, Korea and China are cold too in winter Japanese and Chinese EVs might be the first to take heating into consideration. The need for air condition might pull in the same direction as isolation against coldness has the same effect on overheating.

© Copyright EDISON Consortium. 2009. All Rights Reserved

To conclude a travel range of 150 km could be reduced to only ¼ - less than 40 km - if the trip takes place at a motorway with full speed on a cold winter day. On a day where the heating is not needed or the car is constructed for a heating system not based on the battery travel range can be reduced to 75 km if the speed is 110 km/h. But very few drivers are driving the whole way on motorways. Furthermore the driver would be expected to reduce the speed if he is running short of energy. Therefore it is decided in the work here to accept 80 km as the minimum travel range if drivers are in risk of running out of electricity. For the bigger cars the travel range could be higher, but this extra capacity might be expected to be used for higher speed or a more comfortable temperature. Therefore we will use 80 km as the minimum travel range for all cars.

Even though the cars have these capacities, the drivers will not discharge the battery completely, as they will of course not risk running out of power. For the rebuilt Citroën C1 the manufacture had chosen to help the driver by constraining the speed when the left battery capacity was low. But this does not seem to be a successful solution because the cars risk to be dangerous when they drive too slowly and the drivers find it irritating (Kjærulff, 2011).

Instead the driver will him/herself put in a safe margin, but at the moment we do not know about any analysis showing how little electricity the driver will accept to do with. In the calculations it is assumed that the driver will insist on charging the battery when 20 km of the travel range is left.

2.2 TECHNOLOGY OF THE CHARGING INFRASTRUCTURE

Electric infrastructure is extremely regulated by standardisation because of safety risks. This means that the electric installations have to follow the EU regulation. But these have origins in the former national regulations and standards, which mean that you have some differences in infrastructure across Europe. These differences are mirrored in the way the automotive industry finds solutions to charging infrastructure before these are standardised. But because the cars need to travel and charge all over Europe the industry is quite well aware that coordination and standardisation is needed. The EU commission has set up requirements to the standardisation in which the European countries find together in one common standard for plugs. The work is therefore most about how to coordinate all the national solutions (Foosnæs, 2011a). At the moment the complete integration is not accepted to take place until 2017 with the next generation of EVs. But it is expected to take place faster because the need is urgent. (Information from Claus Amstrup Andersen, Enrisco)

For Denmark the outset for the use of the daily charging facilities will be the existing infrastructure in private homes and in public areas. Changes can be made but they are very expensive for the user and will be an extra investment on top of the costs for the expensive cars. The analyses in this report are therefore first of all based on the possibility to use the existing electric infrastructure.

Charging facilities in private homes, workplaces and other smaller places with few guests or customers need to be based on the normal electric technology available in family houses. First of all it is the one phase 10 Amp socket found everywhere and the 16 Amp socket, which exists as both a 1 phase and a 2 or 3 phase socket. The 1 phase 16 Amp socket is normally used for washing and dishwashing machines whereas a 3 phase socket is used for stoves with an oven. They can both be installed by an electrician if the network for the plug is reinforced with a thicker cable than for the 10 Amp installation.

The resulting effect from these installations is presented in Table 2-2. It also shows how long time it takes to charge the batteries in the cars that are currently in the market. If the car is charged at a normal 10 Amp plug it will take close to 8 hours to charge the small EVs with the normal plug. This can be reduced to a little less than 5 hours if the current is increased to 16 Amp. The real improvement is obtained when the charging infrastructure i changed to a 3 phase 16 Amp installation with which the charging time can be reduced to a little more than 1½ hour.

© Copyright EDISON Consortium. 2009. All Rights Reserved

Table 2-2 Characteristics of different kind of Danish charging installations. Charging times takes into account a 10 % effect loss in the charger (Foosnæs, 2010).

	1 phase	1 phase	2 phases	3 phases	1 phase	Fast charging[1]
Power, V	230	230	380	380	380	
Current, Amp	10	16	16	16	64	
Effect, W	2,300	3,680	7,360	11,040	14,720	50,000
Charging speed, kwh/h	2.3	3.68	7.36	11.04	14.72	50
Charging time	Hours	Hours	Hours	Hours	Hours	Minutes[2]
Charging time, 16 kWh	7.7	4.8	2.4	1.6	1.2	17
Charging time, 24 kWh	11.6	7.2	3.6	2.4	1.8	26
Charging time, 60 kWh	29.0	18.1	9.1	6.0	4.5	64

[1] ChoosEV at Landgreven in Copenhagen. [2] Only charging to 80 % level of full battery.

Unfortunately at the moment the new EVs actually at the market are not supporting charging by 3 phases. The plug on the car and the technology inside the EV is only supporting one phase. It is supporting both 1 phase AC current and 50 kW DC current (Figure 2-1). The reason for this is possibly that the actual EVs at the market are either French or Japanese where they do not use 3 phases for high effect supply as we do in Denmark but 1 phase DC. When the German EVs come to the market they are expected to use the proposed standard from Germany which is in accordance with the Danish needs (Foosnæs, 2011a).

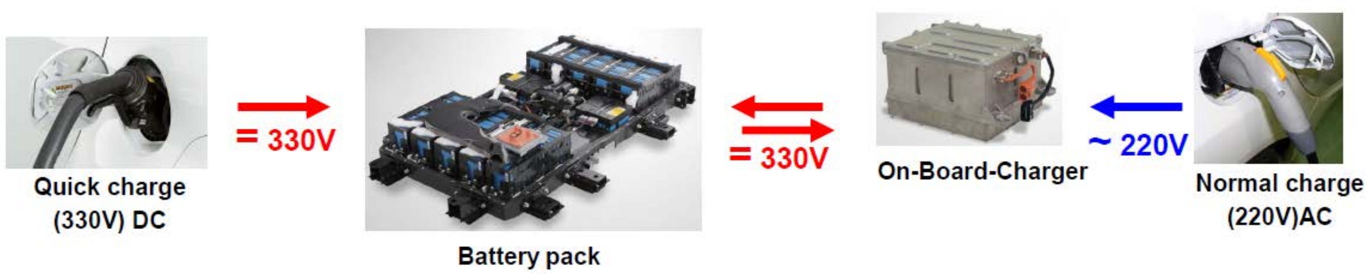


Figure 2-1 Illustration of charging with a plug on each side of the car, one for DC current from a charger (from right), and one with one phase AC current from the network with the charger onboard (from left). (Foosnæss, 2011d)

A company selling or leasing EVs is normally offering the customer a charging pole at home, typically as a wall hanged installation (ChoosEV, 2011, Better Place, 2011, Tesla, 2011). In Denmark a one phase 16 Amp installation is normally offered. This installation is chosen because a 10 Amp installation is too slow for the EV to be charged during an 8 hour night (Table 2-2). A 3 phase installation is on the other hand not necessary except for the Tesla Roadster, and is as mentioned not available at the moment. The small family cars will with 16 Amp can easily be charged before eight hours has passed, and there is room for a little intelligent charging included in the 8 hours if the battery was close to being empty when it arrived at the recharging spot. But for the medium size family car with a 24 kWh battery a 2 or 3 phase installation might be preferred to have more time for intelligent charging.

© Copyright EDISON Consortium. 2009. All Rights Reserved

If an EV driver is commuting long distances and therefore need to charge at the job at 16 Amp 1 phase installation will also be a good thing to have especially because this might offer intelligent charging along with full charging in a 7-8 hour working day.

When an EV driver visits other activities like a shopping centre or recreational place and needs to charge to get back home much less time will be available and a higher charging effect might be attractive.

To illustrate the need for charging facilities at public areas a relevant question is therefore how far it is possible to drive after a charging period of 20 minutes, which is a typical short shopping period and after 1-2 hours which can represent other recreational activities.

Table 2-3 Driving distances after a certain time at 2 different levels of energy consumption per km and with different kind of charging installations. A charging loss of 10 % is taken into account.

	1 phase	1 phase	2 phases	3 phases	1 phase Direct current?	Fast charging
Charging speed, kwh/h	2.3	3.68	7.36	11.04	14.72	50
Driving range in km at a 135 Wh/km consumption level	7.4	7.4	7.4	7.4	7.4	7.4
Km per hour charging	15	25	49	74	98	333*
Km per minute charging	0.26	0.4	0.8	1.2	1.6	5.6
Km per 20 min charging	5	8	16	25	33	111
Driving range in km at a 107 Wh/km consumption level	9.4	9.4	9.4	9.4	9.4	9.4
Km per hour charging	19	31	62	93	124	422*
Km per minute charging	0.32	0.51	1.0	1.6	2.1	7.0
Km per 20 min charging	6	10	21	31	41	141*

* The figure is theoretic as the car can only be charged up to 80 % of the capacity which is 185 respective 150 km.

Foosnæs (2010) recommends using a consumption level of 135 Wh per km driven or 7.41 km per kWh charged. This figure is based on a compromise between the energy consumption of an elderly Citroen Saxo EV which is consuming 175 Wh/km and a theoretical figure from the Department of Energy suggesting 100 Wh/km. However, 150 km Travel range on a 16 kWh as mentioned for for instance the Citroën C1 is giving 107 Wh/km or close to the consumption level mentioned by the Department of Energy. 135 kW/km is much in line with the medium size EV with a 24 kWh battery.

On top of the 107 or 135 kW/km a power loss of 10 % in the charger has to be taken into account, which means that the electric system needs to deliver 118 respectively 150 Wh to drive one km (Foosnæs, 2010).

When an EV driver visits a private home or a firm for business and needs to charge to get back home he will normally have to use a 10 Amp socket. According to Table 2-3 the EV will get power to drive 15-19 km per hour's visit depending on the consumption. If a vehicle needs to be charged when the driver is out shopping for 20-40 minutes a one phase 10 Amp installation will only offer 5 km per 20 minute's and that may not be sufficient. A 3 phase 16 Amp charging pole will be a much better option because it offers 25-31 km per 20 minute's charging. We will come back to what this means in practise in chapter 5.2.

© Copyright EDISON Consortium. 2009. All Rights Reserved

On a long distance travel 25-31 km extra kilometres for a 20 minute's stop will not be sufficient. In this situation a fast charging station or a battery swapping station is necessary. The ChoosEV fast charging station of which the first has been established at Landgreven in Copenhagen could be a solution. By visiting this the battery can only be charged up to 80 %. It takes around 17-26 minutes if the battery allows the high charging effect (Table 2-2). The limit of 80 % is set up not to over-charge any of the battery cells (Information from ChoosEV in 2011).

The charging facility offering 64 Amp is mentioned at different homepages about EVs but is not in use in Denmark at the time of writing. It is expected that charging poles with a capacity of 48 Amp in 3 phases will be a possibility in private homes in Denmark but they will need reinforcement of the grid. At the moment when the battery capacity is 16-24 kWh this high charging effect does not seem to be necessary at private homes. Even when the capacity goes up to e.g. 40 kWh 3 phase 16 Amp sockets should be enough. Charging poles at some public activities with 48-64 Amp in 3 phases might on the other hand be a good option.

Real fast charging where the battery is charged to full capacity in 5-10 minutes is not developed yet. Instead the battery swapping system developed by Better Place is an option. With this the car can have full capacity in 5 minutes.

© Copyright EDISON Consortium. 2009. All Rights Reserved

3 DATA FOR THE ANALYSES

To be able to analyse the possibilities of using EVs to cover the transport needs, it is necessary to analyse data regarding the use of conventional cars, as there is not enough EVs on the market, and thereby not sufficient data, to analyse the actual use of EVs. In this chapter the available Danish data for these analyses is presented. It is shown that none of the available data as they are collected are fully useable for the analyses in this report. Therefore it has been necessary to change the data by data modelling before they can be used. This is presented in this chapter.

3.1 DATASET AVAILABLE

In Denmark two datasets are relevant to use for analysing travel patterns of passenger cars, the Danish National Travel Survey (NTS) and the AKTA data. The AKTA data is data collected using GPS tracking during a road pricing experiment in Copenhagen in 2002-03. None of these two data sources are ideal for the purpose, but together they can illustrate the travel pattern. The advantages and disadvantages of the two datasets for passenger cars are presented here.

1. The NTS data are interview data about travel behaviour of the population, collected daily for over 15 years (Transportvaneundersøgelsen, 2011). The number of interviews is large (more than 100,000 interviews), they are representative for the population, and they contain much information about travel behaviour. The sampled respondents are called by telephone and are asked about their trips the day before the interview. The trips are reported one by one from the first trip in the morning. For each trip information is collected about time of departure, transport mode, trip length, duration, destination and activity at the destination. Furthermore some background information about the respondent and the family is collected. The problem for the current analysis with the dataset is that the information follows the respondent's behaviour and not the travel pattern of the car, because the Danish NTS is collected by interviewing individuals and not everybody in a household as in many other countries. Therefore no information exists about driving activities by drivers other than the respondent driving the car as driver. In addition, the interviews only report the respondent's behaviour on one particular day.

2. The AKTA data is GPS-based data following the cars (AKTA data). They were collected in 2001-2003 as part of a road pricing trial. A total of 360 cars were followed by GPS from 14 to 100 days as a base period for comparing with the trial period. These data contain information about travel patterns of the cars and the variation during a week and partly also during a month. The dataset, however, includes significantly fewer cars and the detailed information about the trips is, apart from the exact geographical positioning, very modest. The most important disadvantage is, however, that it only includes cars belonging to families with one car, families living in Greater Copenhagen, and only families active at the labour market. It means that data are not representative.

For freight transport no similar dataset with daily driving exists. The only available data is based on reading the odometer at the yearly inspection. Therefore, for this kind of vehicles only the yearly mean kilometres is known so the individual differences over the day and week is unknown.

3.2 SUITABILITY OF THE NTS DATA FOR ANALYSING TRAVEL BEHAVIOUR OF EVS

For the analyses of travel behaviour NTS data is used for the period 2006-10 for families with car and with at least one driving license held by a member of the families. The dataset consists of 53.325 interviews representing 72.577 cars.

© Copyright EDISON Consortium. 2009. All Rights Reserved

The fact that only individuals and not households are interviewed in the NTS means that we only have information about how much the respondent is driving by the car. Therefore it is impossible to know how much the car is driven by others than the respondent. It has therefore been necessary to construct a dataset from which the travel pattern of the car can be analysed.

As an outset of the analyses it is assumed that for singles and families with one car and one driving license the car is driving as many kilometres as the respondent. They are making up 19 % of the families and 14 % of the cars (Table 3-1)

The same is assumed for families with two cars and two licenses and with more cars and a similar number of licences. They make up 24 % of the families and 36 % of the cars (Table 3-1). The assumption is correct if each driver is always driving his or her own car or if it is more or less random how the partners share the cars. But it is not the case if one partner is e.g. using the big car for daily commuting at a short distance and for other short homebound trips and the partner is using the small car for a longer commuting distance and is driving the big car when the family is travelling at long recreational trips. In situations like this the big car is driving more kilometres than the respondent if the person maintaining the home activities is interviewed and the small car is driving less than the respondent if the person with the long travel distance is interviewed. Because of such changes of car drivers of the two or more cars of families the kilometres calculated from the respondents will show a bias against more equal distribution of kilometres than is the case for kilometres per car. The size of the bias of this kind is not analysed for this report but is assumed to be of limited effect on the results.

Table 3-1 Share of families and share of cars in families of different types according to number of cars and number of driving licenses. With shadow is showed those types of families which are not included in the analyses. TU data

	Cars	Licenses 1	2	3	Less than cars 4+	Same as cars 4+	More than cars 4+	Handled	Not handled
Share of families	1	19%	45%	4.2%			0.5%	68%	0.5%
	2	1.0%	23%	3.6%			0.5%	24%	4.1%
	3	0.1%	1.5%	1.0%			0.3%	3%	0.3%
More than licenses	4+	0%	0%	0%	0.0%			0.7%	
Same as licenses	4+	0%	0%	0%		0.1%		0.1%	
Less than licenses	4+	0%	0%	0%			0.0%		0.01%
All								95%	4.9%
Share of cars	1	14%	33%	3.2%			0.4%	50%	0.4%
	2	1,4%	33%	5.3%			0.7%	35%	6.0%
	3	0,2%	3,2%	2.2%			0.6%	6%	0.6%
More than licenses	4+	0%	1.4%	0.7%	0.1%		0.0%	2%	0.01%
Same as licenses	4+	0%	0%	0%		0.3%		0.3%	
Less than licenses	4+	0%	0%	0%			0.0%		0.02%
All								93%	7.0%

For families with more cars than members with driving licenses it is assumed that a car is driving as much as the respondent. This will in some families not be the case because the respondent is changing his driving between the cars. In other families it is more or less correct because the definition of having a car is that the respondent has ‘access’ to a car and in many cases the respondent has access to a car which is used by other persons in the household who is not a part of the family. In these cases the respondent and the car is driving the same number of kilometres. 2.5 % of the families and 4.9 % of the cars belong to this kind of respondents.

© Copyright EDISON Consortium. 2009. All Rights Reserved

In all families with access to more than one car it might be expected that the family will change use pattern if one of the cars is an EV. If a planned trip is longer than the travel range of the EV the driver might take the conventional car instead of using time on fast charging.

For households with more licenses than cars it cannot be assumed that the car is driving the same distance as the respondent. For a family with one car and 2 drivers the car is driving twice as much in mean as the driver. And if three members of the family have a license the car is driving three times as much as the respondent in mean.

According to Table 3-1 most information about driving distances are missing for families with one car and two or three driving licenses that make up 49 % of the families and 36 % of the cars. To make the NTS data usable for analysing travelling behaviour of the car in a one car family with two or three drivers a new dataset for the car is constructed. This is described in the chapter below.

Situations with two cars and 3 licenses in the family cannot be handled in the same way as families with one car. A dataset for these situations is not constructed. Families with two or more cars and more cars than driving licenses make up 5 % of the families and 7 % of the cars. ¾ of these are families with 2 cars and 3 driving licenses (in Table 3-1 they are marked with grey). If such a family invests in an EV they will as in the case of the family with two cars and two drivers assumable be able to share the cars so that the person who needs to drive longer distances at an actual day will use the conventional car. What can be added to the conclusion about the EV travel behaviour by adding this extra person's driving to the data is therefore limited.

This kind of families is most often a couple with an adult child holding a driving license and living with his/her parents. And most often the two parents will 'own' the car and the child might only drive when the cars are not in use by the parents. If the family has an EV the child will furthermore only be allowed to drive a car if it is possible to do it either because the conventional car is not used by another member of the household or because he/she can use the EV without getting problems with charging it. So to say the child's demand for driving will not influence the family's decision about investing in an EV very much. It will primarily be the need for driving of the parents that influences the decision; the adult child can use it if it is available and charged. For the two car families with 3 licenses the respondent is left out of the analysis if he/she is not a part of the couple.

Families with more than 3 licenses are left out of the analyses (1.6 % of the cars).

3.3 CONSTRUCTION OF A DATASET FOR THE CAR IN FAMILIES WITH 2 DRIVING LICENSES

For the families with one car and two licenses it is described how a dataset for analysing the travel behaviour of the car is constructed based on the travel behaviour of the respondents.

For the construction it is assumed that the respondent has a partner who has travel behaviour similar to another person in the dataset who share personal and familiar characteristics with the driver and his/her family. In the following this person is mentioned as a partner both if they are a couple and if they are related differently (two brothers or mother and son for instance).

This other person will not be able to travel by the family car as driver in those periods where the respondent is away from home using the family car as driver. Therefore the construction of the dataset is made such that the assigned spouse is not allowed to drive as driver in the same period as the respondent. In practice this is handled so that the day is divided into time-bands. If the respondent is using the car during a time-band it is assumed that it is not available for the partner in this time-band. The chosen time-bands are the period before 6:30 in the morning, the period after 20:30 in the evening and hourly

© Copyright EDISON Consortium. 2009. All Rights Reserved

periods during the daytime (6:30-7:30, 7:30-8:30 etc.). Furthermore it is assumed that the couple is not changing the car outside home. All data-handling is therefore based on tours and not on trips. If a driver and a passenger are changing seats so that the respondent is only driving in a part of the tour the respondent is handled as driver at the entire tour if he/she starts the tour, and as driver and therefore left out if he/she starts as passenger.

The characteristics of the driver and the person he/she is combined with in the dataset are:

- They have 1 car and 2 driving licenses in the family
- They are interviewed on the same weekday (working day, Saturday, Sunday)
- They live in the same region of the country (Copenhagen region, Zealand, Bornholm, Funen, Southern, Eastern, Western or Northern Jutland)
- They live in a city of similar size (Central Copenhagen, Copenhagen suburbs, 3 cities>100,000 inhabitants, cities 20-100,000, 2-20,000, <2,000)
- They live in the same type of family (single/couple, with/without children, others)
- The person who is assigned as partner has to have the correct gender and age group as the partner of the respondent according to the interview (18-24, 25-39, 40-59, 60-69, 70+ years)

These criteria for assigning the partner are chosen because they are known to be of importance to how much a person is travelling and how much he/she is driving by car (Christensen and Fosgerau, 2002). The main occupancy of the partner would have been relevant, but it is unfortunately not reported for the partner in the interview. Age class is therefore used as a substitute for main occupancy. The region is not important if the size of the city is included in the criteria except for Zealand (because it is a part of the labour market of Copenhagen) and for Bornholm (because it is a small island far isolated from the rest of the country). But it is decided to take it into account to make it possible to regionalise the analyses afterwards, especially for Bornholm.

When a dataset is constructed based on these assumptions almost 90 % of the respondents are assigned to a partner from the dataset. If travelling day and gender are fixed, but other criteria are accepted not to be satisfied 94 % of the respondents can be assigned to a partner. If the gender criteria is given up the assign rate can be increased to 99 %. It is chosen in the dataset to require both gender and travelling day to be satisfied. Around 1450 person are therefore left out of the constructed dataset.

The day is required because the travelling pattern through the day is very different at weekdays and in weekends. The reason to require the gender satisfied is that it is known that the male is more often driving as driver than the female partner (e.g. Hjorthol & Næss-Kjørstad, 2006, Polk, 2004, and in unpublished analyses on the Danish NTS data). A combination of two women will therefore be rather erroneous if the driving partners in the family are a man and a woman. The reason why it is not possible to get more than 94 % of the persons assigned to a partner is that the response rate is lower among males than females so the dataset consists of more women than men.

The resulting dataset includes all respondents twice, once as a main person in the dataset and once as a partner. Therefore each observation is only included in the new car-dataset with half of the original personal-weight[1]. To compensate for the reduction of the dataset with the 1450 persons for which no partner is assigned the weighting factor of the cars is increased according to the dropped families. To do this it is assumed that those who are included in the dataset are representative for

[1] All observations in the dataset has a weight which is used to multiply the observation with in analyses so that the dataset makes up the whole car park. It is needed to compensate for differences in response-rate for different segments of the respondents.

© Copyright EDISON Consortium. 2009. All Rights Reserved

those who are dropped out. It is assumed that this is more correct than including them with the bias of assigning a female to another woman who is known to live together with a male.

3.4 CONSTRUCTION OF A DATASET FOR THE CAR IN FAMILIES WITH 3 DRIVING LICENSES

To construct the driving of a car which belongs to a family with 3 driving licenses is more complicated.

Families with 3 driving licenses and only 1 car make up two different kinds of families, a couple living together with a single person (typical parents with an adult child living at home), and three family members living together without any of them being coupled (for instance two adult children with one parent having a driving license). The last family type is only represented by 162 respondents in the dataset so they are left out.

In the situation with the couple either a person in the couple or the adult child / third family member is interviewed. The assigning of the 3 persons to a common car is done in two stages. First all the interviewed persons in a couple are combined and the common travelling is calculated. Afterwards the third person is added to the couple. The third person is in most cases a son or daughter but in few cases it can be a parent or a sister or brother to one of the persons in the couple. The couple is in few situations also made up by two men / women.

The interviewed persons in a couple are combined with another person in a couple with correct characteristics found in the same way as in the paragraph above. The only difference is that the family type is not included as we already know they are a part of a couple with a third person in the family. 72 % of the 1472 respondents are assigned to a partner when all characteristics are met and 89 % are assigned when region, age and urban size are left out so that day and gender are the only obligations. As with the families with 2 driving licenses only women are left in the data set at this level. If the assignment is going on till a level where the day is the only matching factor 95 % of the respondents have been assigned a partner. It is decided to include the 1310 respondents who are matching on both gender and day.

When the respondents are assigned to a partner their common driving periods are registered. The third person can only drive in periods when none of the two persons in the couple are driving.

The third person should be assigned to the couple by new matches. As mentioned in the former paragraph persons in the couple is included twice as both respondent and as assigned person. Explained in another way the data set represents both the male and the female in the couple. Therefore each of the third persons has to be assigned twice to the couple, once to each of the persons in the couple. The dataset with the third person is only including one person and should in principle be half the size of the data set with the couple. In practice the third dataset is only making up 611 interviews which are much fewer observations than half of the observations in the couple-data set. This is due to a very low response-rate of young adults.

The assignment can be done in different ways. It has been decided to split the data set with the couple into two parts, one with men and one with women as respondents. For the third person it is known both which man and which woman the person is in family with (all third persons in the dataset are in family with one of each gender). Firstly, the third person is assigned to one of the men and afterwards to one of the women as respondents. When all the criteria are used 66 % of the third persons are coupled to a man and 64 % are coupled to a woman. When only the weekday is used as criterion 91 % of the third persons can be assigned to a father respectively to a mother. However, this means that only 85 % of the men / women in the couples are assigned to a third person due to the higher number of persons in couples than third persons.

© Copyright EDISON Consortium. 2009. All Rights Reserved

In total 1112 respondents of the original 1472 respondents (76 %) are assigned to both a partner and to a third person. 360 respondents are left out. As with the families with two driving licenses the lower assignment rate is compensated by a higher weight for the resulting cars in the data set. The reason for the much lower share of assigned persons is partly the uneven response-rate of men and women and of young adults, and partly the much fewer persons in the data set. The less people in the data set the more difficulty it is to find a person who fits into the free travel periods.

The constructed dataset of the car is a dataset including all trips of the three persons in the constructed dataset during the day.

© Copyright EDISON Consortium. 2009. All Rights Reserved

4 CHARGING EVS

In the first years until the charging infrastructure is established outside the user's own home, it will be relevant for potential owners of EVs to consider whether they can avoid charging during the day. As the charging infrastructure becomes available at workplaces, in city centres etc., the need to charge the car away from home will only be a source of irritation and only on rare occasions considered a barrier as such. The real barrier in this future situation we expect to be the demand for fast charging when the trip is longer than the travel range of the EV.

In this chapter the need for charging outside home and the demand for charging at simple charging poles and for fast charging will be analysed for different types of families. Furthermore the possible availability for intelligent charging is analysed.

4.1 CHARGING AWAY FROM HOME

The share of cars that needs to charge in daytime depends on the travel range of the EV in the way it is driven. It also depends on the number of drivers that share the car (Table 4-1). For all the calculations it is expected that the driver is charging before 20 km is left in the battery to be sure not to run out of electricity.

As mentioned in chapter 2.1 the travel range is only around 80 km if the weather is very cold or the driver uses a motorway driving 110 km/h or more for a longer part of the travel. In this situation up to a third of the cars that drive at the actual day will need to be charged.

Table 4-1 Share of the cars driving at the actual day which need to be charged during the day dependent of the number of cars and driving licenses in the family. TU data

	80 km	120 km	150 km	180 km
1 car / 1 license	23%	11%	6%	4%
1 car / 2 licenses	29%	14%	9%	6%
1 car / 3 licenses	33%	15%	8%	5%
2 cars / 2 licenses	33%	15%	10%	7%
3 cars / 3 licenses	27%	13%	10%	7%

If the EV most of the time is driving in cities or on roads outside the motorway where speed restriction is 80 km/h the travel range will be increased to around 120 km if the heating system is used in parts of the time. This quite normal situation will result in a need to charge in the running of the day for 11-15 % of the drivers. However in summer-weather with speeds less than 80 km/h the EV can use the full travel range which means that only 6-10 % needs to charge outside home if the travel range is 150 km and 4-7 % if the travel range is 180 km.

For cars belonging to singles the need for charging outside home is lower than for other families at all travel ranges. Families with two cars and two drivers have the highest need to charge during the day. A family with only one car and two or three persons need to charge nearly as often outside home as the two car families. With a travel range higher than 80 km they need to charge outside home in 50 % more days than singles. The reason why the families with 3 licenses need to charge less than families with drivers might be because of the difficulties with combining 3 family members around one car.

The reason why each of the two cars in a family with two cars need to charge as often outside home as the car in families with only one car is due to the very high purchase tax on cars in Denmark which means that that a family is not purchasing a car number two without really needing it. (Christensen, 1994)

© Copyright EDISON Consortium. 2009. All Rights Reserved

In a two car family it might however, be possible to share the car in another way if the family is purchasing an EV so that the EV does not need to be charged as often as shown in Table 4-1. Unfortunately it is not possible show how relevant this is with the actual data.

Table 4-2 Share of cars not driving at the actual day. Share of cars that need to be charged outside home during the day dependent on the travel range. TU data

	Not driving	80 km	120 km	150 km
Copenhagen and Frederiksberg Municipalities	39%	7%	3%	3%
Copenhagen suburbs	24%	11%	2%	4%
3 cities >100,000 inhabitants	30%	8%	3%	6%
< 100,000 inhabitants	25%	12%	4%	7%

Table 4-2 shows that the need for charging outside home is rather similar in different city sizes. In the biggest cities less will need to charge outside home if the travel distance in practise is only 80 km. With travel ranges over 80 km there is very little difference between the cities. A breakdown of the data to more city sizes is not changing the picture. This indicates that the travel pattern of the population means that there is no reason to expect EVs to be specially 'city cars'. They are equally suitable for all sizes of cities if the theoretical travel range is as the new generation of EVs.

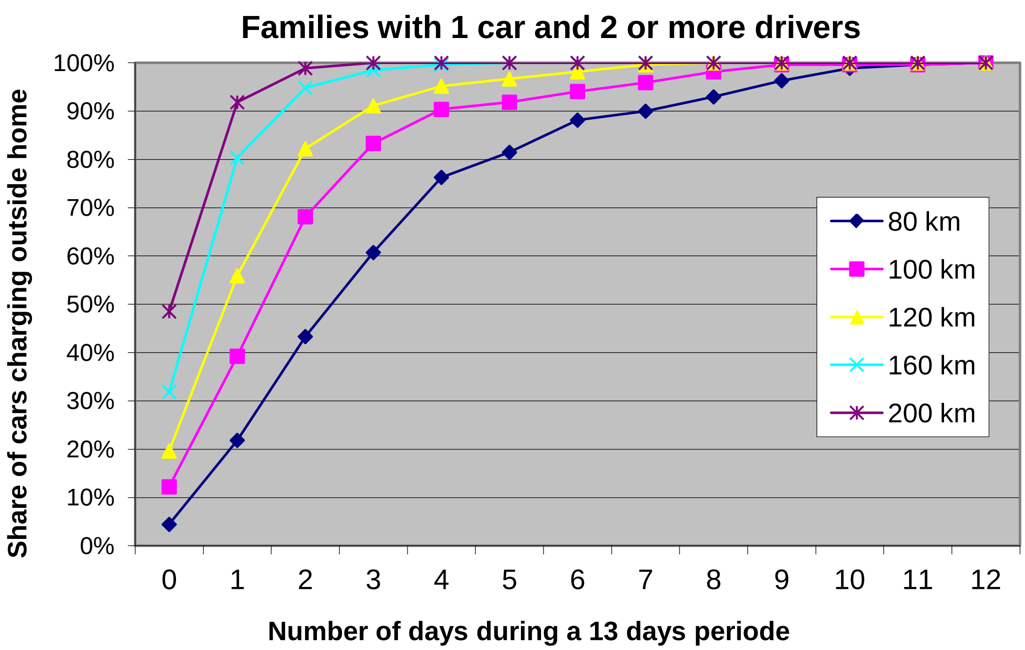


Figure 4-1 The number of days during a 2 weeks period the respondent in maximum need to charge outside home. Each curve follows a certain travel distance and shows the share who needs to charge in no more than one day, no more than two days, no more than 3 days etc. Represents a family with one car and 2 or more driving licences in Greater Copenhagen. Akta data.

However, these results only show how often a family needs to charge at an actual day. Analyses of travel behaviour over longer periods show that people change travel pattern from day to day so that only few days are similar (Schönfelder & Axhausen, 2010, Stopher et al, 2007, Stopher et al, 2010, Stopher, 2011). Pearre et. al. (2011) has followed more than 400 conventional cars in Alberta for a year to find out how often they will need to charge outside home or the owner will need to

© Copyright EDISON Consortium. 2009. All Rights Reserved

adapt by e.g. using another car. They show that only 9% of the cars never drive more than 100 miles at any day (160 km) during the year and only 32 % are driving 100 miles up to 6 times a year. If a similar driving pattern is the case in Denmark nearly no cars will be able to drive a hole year without having to charge outside home, especially when it is taken into account that Danish cars drive 20 % longer per year than American.

To illustrate the effect of changing travel patterns over a longer period the above mentioned AKTA data can be used. They only represent families in the working age population and only in the Copenhagen region. Some of the cars are followed for two weeks in the control period others for a much longer period. Therefore a 13 days period is used to show the changes as this is the longest period for which all the needed information exists.

It appears that very few cars can avoid charging during the day at least once during such a fortnight period. Less than 20 % of the families with 2 or more drivers can avoid charging outside home in periods where they cannot use the full capacity of the battery (Figure 4-1). And even with full capacity 60-70 % will need to charge outside home one or more times a week. With a typical driving range of 120 km/h 10 % will need to charge every third day.

Less singles will need to charge outside home in a fortnight period. 70 % will need to charge at least once and 10 % will need to charge a couple of times or more over the two week period (Figure 4-2).

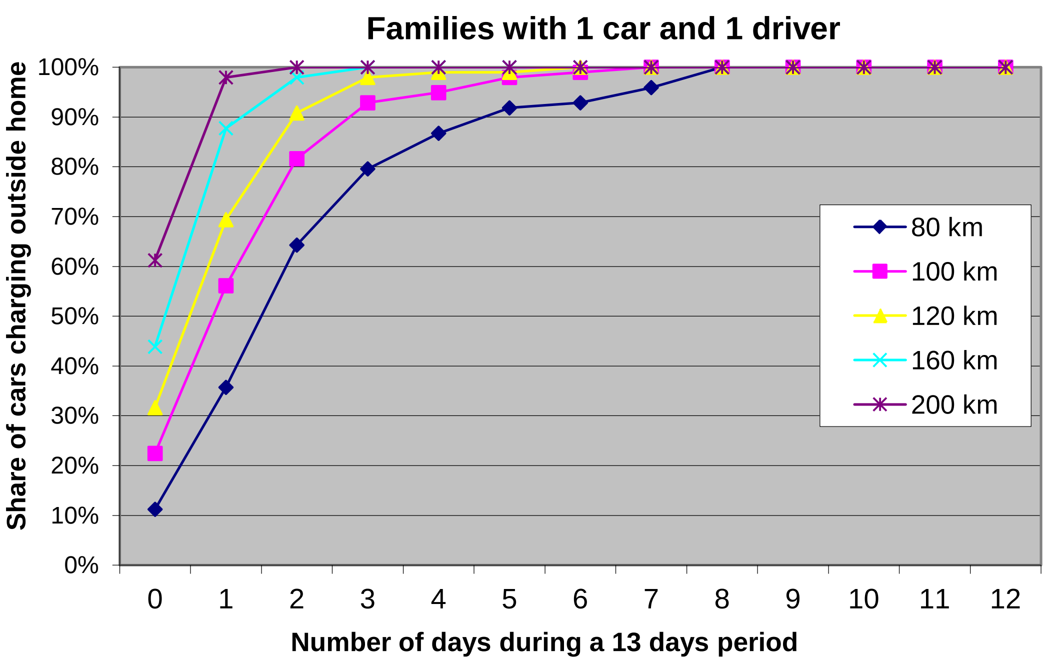


Figure 4-2 The number of days during a 2 weeks period the respondent in maximum need to charge outside home. Each curve follows a certain travel distance and shows the share who needs to charge in no more than one day, no more than two days, no more than 3 days etc. Represents singles in Greater Copenhagen. Akta data.

4.2 POSSIBLE PARTICIPATING IN INTELLIGENT CHARGING

Seen from the electric system's point of view it is very relevant to know if the driving pattern is suitable for using as a part of an intelligent charging system. The vehicles can be ready for intelligent charging in two ways

© Copyright EDISON Consortium. 2009. All Rights Reserved

- When the EV is available for a longer period where it is not driving at all, e.g. a day, a weekend, or a holiday the battery can be used as storage which can be charged and de-charged.
- When the charging of the EV after the end of the travelling of the day can be postponed to later in the night or even to the day after.

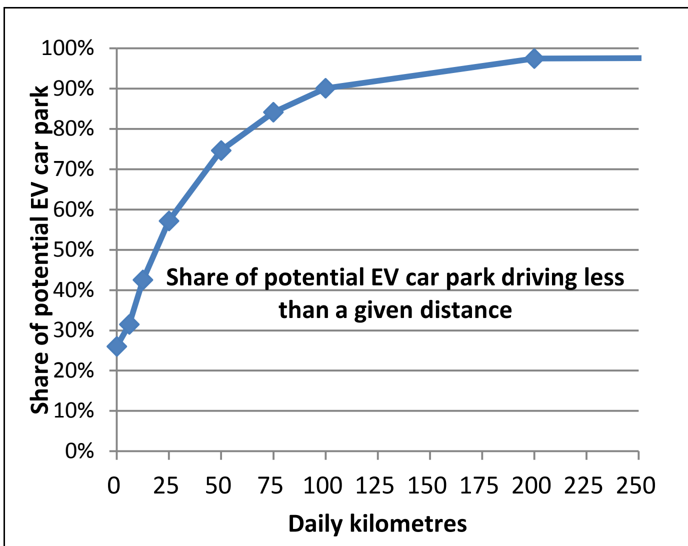
According to Table 4-3 26 % of the cars are not driving the actual day. Normally they are parked at home. These cars will if they were EVs be available for the grid for intelligent discharging and charging, if this is allowed by the car manufactures and accepted by the owners. Families with only 1 car and 2 or 3 drivers are using the car much more often than the rest. The car is only staying at home 6 % of the days if 3 drivers share the car, and 15 % of the days if two persons share the car.

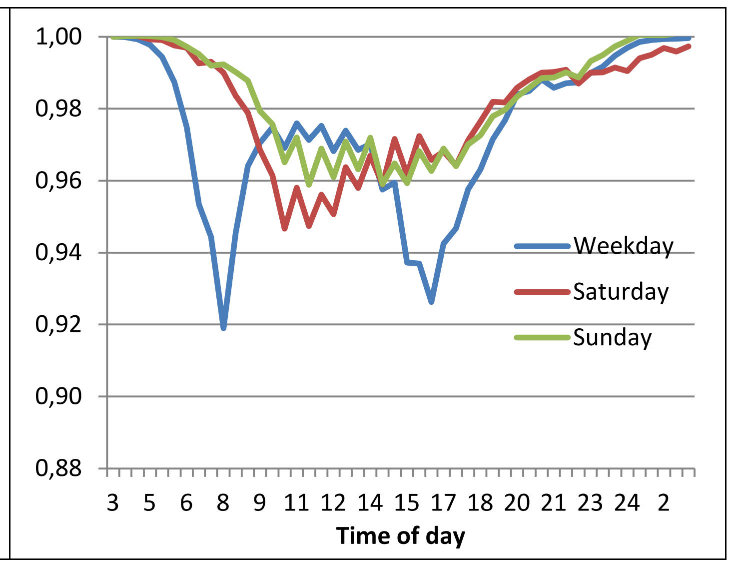
Cars are most often at home on Sundays (Table 4-3 and Figure 4-3) and in the central part of Copenhagen (Table 4-2).

Figure 4-4 shows that the travel distance at the actual day of most of the cars is rather low. 75 % drives less than 50 km and will therefore not need to charge more than half of the days in mean. Of these the 25 % is due to no driving at all. With an agreement with the EV owners it is possible to postpone even night charging substantially in periods with no wind.

Table 4-3 Share of cars not driving the actual day dependent on number of cars and licenses and on weekday respectively. TU data

Number of cars	Number of licenses	Share of cars not driving	Weekday	Share of cars not driving
1	1	38%	Working day	22 %
1	2	15%	Saturday	32 %
1	3	6%	Sunday	42 %
2	1	135%		
2	2	29%		
3	3	29%		
Mean for all				26 %





© Copyright EDISON Consortium. 2009. All Rights Reserved

Figure 4-3 Distribution of the travel distances. Share of potential EVs that drive less than the shown distances. TU data	Figure 4-4 Share of the potential EVs parking at a given time of the day. TU data

Fejl! Henvisningskilde ikke fundet. show that at a given time more than 92 % of all cars are parked. Even in the middle of the day 95 % of the cars are parking. And after the afternoon peak which is not ending until close to 8 pm 98 % is parked. If intelligent charging with charging and discharging can be organised it will be no problem for the travel and parking pattern of the cars.

Of course some of the cars need to charge during the day time. 10 % of the kilometres are run by cars needing to charge because they drive more than 100 km on a given day. These 10 % will be distributed over at least 10 hours with more than half as fast charging. But if the fast charging is battery switching the charging of the batteries can be postponed until night time. So at a given time at least 82 % of the cars could be available for the grid for intelligent charging if the drivers are willing to couple to the network when they do not need to charge. Figure 4-5 shows how the charging can be distributed over the day and week dependent of the travel range. Only the needed charging during the day is placed there. The night charging is placed after midnight in the example. Be aware that a bigger share of the immediate charging is higher from Friday to Sunday.

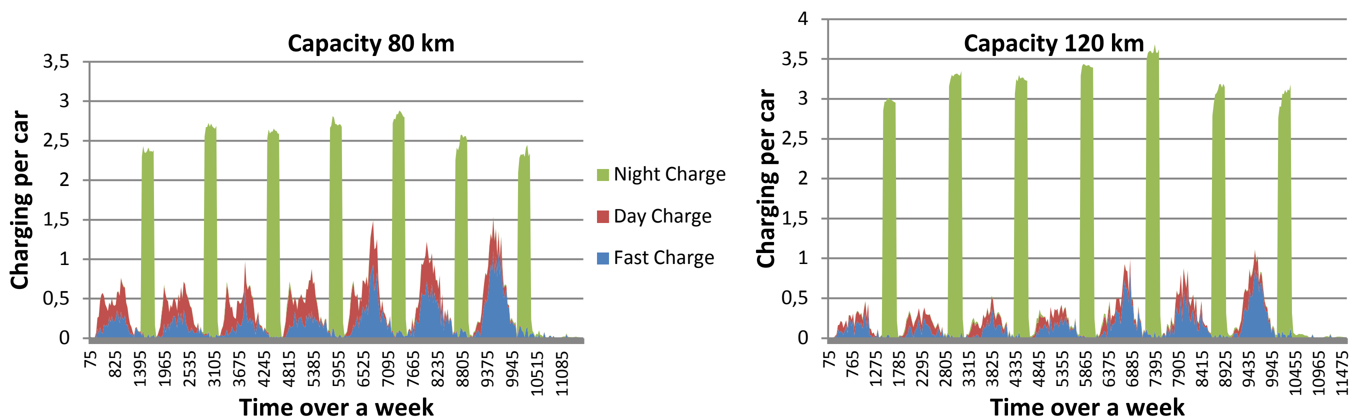


Figure 4-5 Distribution of charging over a week if all cars only charge when they need, and if all night charging is placed after midnight and distributed evenly over the rest of the night. Shown for families with 1 car and with two different travel ranges. Akta data

4.3 CHARGING NEED OR ELECTRIC VANS AND LORRIES

All the descriptions in this report are about passenger cars. However it might also be relevant to have electric goods transport vehicles. This little paragraph is therefore dedicated to a brief discussion of the possibility to use EV vans and lorries.

At the moment no information exists about vans and lorries at the same detailed level as the NTS data for the passenger cars so the calculations cannot be as detailed or as precise. To get a picture of the possibilities data from yearly odometer reading is used which can be used to calculate the daily mean travel distance. It is assumed that the vehicles are only driving 5 working days a week and only 45 weeks a year because the car is not driving during vacations and holidays. If a van or lorry is driven by different drivers it is used more than what is calculated here and the daily mean distance is smaller. This means that the calculation in this paragraph is on the safe side.

Figure 4-6 is illustrating the cumulated daily mean distance of the vans and lorries. Vans with a weight under 3.5 ton gross weight can be driven by people with a license to passenger cars. Close to 90 % of these are driving less than 150 km per day in mean taken over a year with 225 working days. About 70 % are driving less than 100 km and 60 % drive less than 80 km per day in mean. If the travel distance is not varying much from day to day the 70 % of the vans driving less than 100 km might be potential electric vehicles.

For the small lorries under 8 ton and between 8 and 12 ton gross weight less are driving up to 150 km or less per day in mean (80 % / 70 %). But still 60 respectively 55 % drive less than 100 km in mean, which means that more than half of the small lorries might be potential electric vehicles.

Of the big lorries over 12 respectively 18 ton only 30 % respectively 10 % drive less than 100 km in mean. They are therefore not obvious candidates for being electric vehicles. The need for power is another reason for heavy vehicles not to be equally as suitable for electrification.

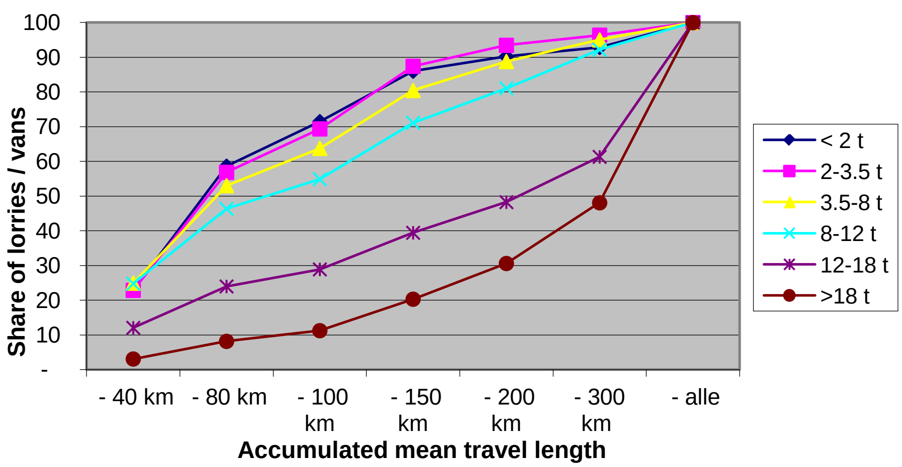


Figure 4-6 Accumulated distribution of the mean travel length of vans and lorries when it is assumed that they drive 225 working days per year. Source: MD database

© Copyright EDISON Consortium. 2009. All Rights Reserved

5 CHARGING POLE INFRASTRUCTURE

In this chapter a possible charging pole infrastructure is analysed. The purpose is to clarify where investments in charging poles should be prioritised, at which activities the highest demand will be and in which parts of the cities. Furthermore it is analysed if it will be profitable to invest in charging infrastructure for private firms. The analyses are separated into two parts, first the demand for public accessible charging poles outside private home at workplaces, shopping centres etc. is analysed, and second the need for night charging in public areas for people living in the central town areas is analysed.

5.1 METHOD

The modelled NTS data for cars is used for the analyses because this includes detailed information about which kind of activities the driver has when the pause of the car takes place. The information furthermore includes in which kind of areas the car stops, in city centres, in low dense urban areas, at the countryside etc. The analyses are based on 47,848 interviews.

The purpose of the calculations is to analyse the behavioural use of a new EV stock in relation to charging. It is therefore important that the analyses, which are carried out are as representative for a future EV stock as possible. For this purpose it is assumed that families with two or more cars will only buy one EV. This is taken into account by dividing the weight for cars in families with two cars by two, and for families with three cars by three etc. The method to use the weight to regulate the number of cars means that the EV and the conventional car available for the household have the same travel pattern. This is of course not fully correct but it is an acceptable assumption for the daily driving and charging and the best we have.

Table 5-1 Activities which are assumed to have a 10 amp wall socket, respectively no charging facilities at all.

10 Amp	No charging facility
Education	Escorting to public transport
Escorting to Activities	Collecting or delivering materials
Post offices, libraries, doctors etc.	Entertainments
Hospitals etc.	Private meetings
Visiting friends and relatives	Walking trips
Sports activities	Weekends and holidays
Other kind of club membership	Transport of goods and passengers
Business travels and services	

It is as mentioned in chapter 2.2 assumed that private homes will install a 16 Amp one pole socket as this is enough for night charging. The same is the case with summerhouses. It is furthermore assumed that the working places will establish a similar installation. Educational areas are not expected to be so helpful to their students so it is assumed that there will only be a 10 Amp sockets available at universities and schools. At shopping centres and in city centres two possibilities are analysed a 3 pole 16 Amp installation and a 50 kW DC quick charger of the ChoosEV type. At private non-EV owner homes and at all other kinds of places with charging possibilities only a 10 Amp installation is expected to be available. Activities without charging facilities and with only a 10 Amp installation are listed in Table 5-1. Please be aware that if some of these activities take place in a city centre the higher effect charging pole will be available instead. To be able to assess the effect of the assumptions alternative installations are tested too.

© Copyright EDISON Consortium. 2009. All Rights Reserved

For the calculations it is assumed that the driver if possible prefers to charge at places where it is most acceptable as at home or at work, and only if this is not possible they will charge at places where it is less convenient, for instance at friends and relatives. Furthermore it is assumed that the best charging poles are located where most customers are expected to use them and where the companies owning the parking areas are professional organisations with interest in customers driving to their firm, first of all at shopping centres. Sport clubs, restaurants and associations are assumed to be less eager to establish charging facilities for their customers and members. At places with very few users such as small parking areas in a forest for instance we will not see charging facilities for the first many years – if ever.

The calculations are carried out in this order:

- First it is analysed if the driver is able to undertake the entire day's activities without any other charging than the night-charging. Summerhouses are also included as places where the driver will install a charger and is therefore night charging at their summerhouse. Only those who have to charge in daytime are included in the further analyses.
- Secondly, it is identified how many can do with charging at home through the day before the car is used for the next activities. These are excluded from the further analyses.
- Secondly, it is expected that the driver will charge at work. It is expected that the employees will be able to make an agreement with their employer about installing a charger at the company's parking area if they need it because of a long commuting distance.
- Shopping centres and city centres are places with high concentration of customers and therefore they are expected to be equipped with charging poles as the first. These are assumed to be the places the drivers will prefer to charge next.
- The rest of the activities are less attractive and should be taken together. Visiting friends and relatives are however one of the most common activities and are normally taking place over several hours. Charging the EV will therefore be a possibility which is therefore included before the rest of the activities.

For the calculations it is accepted that the car is charged at for instance a shopping centre even when it could do with being charged at friends later on. In practise very few can do with charging at shops or other activities without having charged at eventual other activities earlier.

The main calculations are made with the small EVs which are at the moment at the market with a travel range of 150 km and a charging speed of 107 Wh/km at 16 Amp. As in the chapter above it is assumed that the driver always wants to have a margin of 20 km to be sure not to run out of electricity. Furthermore it is assumed that nobody bother to start charging for less than 10 minutes, and two minutes of the pause is used for starting up charging and one for de-coupling. Only pauses with at least 13 minutes are therefore taken into consideration. The calculations are carried out with the new EVs which have a travel range of 150-185 km. But as described in chapter 2.1 the travel range can be shorter at high speed and in cold weather. Most often the travel range is less than the maximum. We use a travel range of 120 km as a typical mean level. The analyses are also made for a very low travel range of 80 km. If the car has a shorter travel range than maximum it still has to be charged up to the full travel range of the relevant car type.

In the calculations in chapter 5.2 it is expected that the EV is fully charged during nights. The need for charging facilities for home charging at night will be taken up in chapter 5.3.

5.2 NEED FOR CHARGING AT DIFFERENT ACTIVITIES

If the car has a maximum travel range of 150 km 94 % will not need to charge elsewhere than at home at night and only 2 % will need to fast charge because they cannot get enough electricity at activities during the day (Table 5-2). If the travel range is

© Copyright EDISON Consortium. 2009. All Rights Reserved

reduced to 120 km 10 % need to charge outside home and 4 % need to fast charge. If the travel range is reduced to 80 km this will result in a need for charging outside home for up to 21 % and 9 % will need to fast charge.

Table 5-2 also illustrate where those who do not need to fast charge will charge on top of night charging. At a 120 km travel range which is expected to be a typical situation in Denmark 10 % will need to charge outside home at night and 3.8 % will need to fast charge. 6.1 % can do with charging normally during the day. Of these 1.4 percent points only need to charge at home and 2.4 percent will charge at their job. Only 0.7 percent will charge at a shopping centre or in the city centre. Of these 0.1 percent will need to charge both at work and at shopping or city centres. About the same share will need to charge at visiting friends and relatives (0.8 %) or at others of the day's activities (0.7 %).

Table 5-2 Share of respondents who can manage their daily ativitites with charging at home (first row) and who need to fast charge (last row). For the rest is shown the share who need to charge only at home during the day, who also need to charge at work, who need to charge at a shopping centre or the city centre or eventually this combined with charging at work etc. TU data

Travel range:	80 km		120 km		150 km	
No need for charging during the day	79 %		90 %		94 %	
Home charging during the day	2.8 %	at	1.4 %	at	0.9 %	at
Charging at work (eventually on top of at home)	5.1 %	charging	2.4 %	charging	1.4 %	charging
Charging at shopping or City Centre (evt. on top of home and work)	1.4 %	poles	0.7 %	poles	0.4 %	poles
Charging at visits (evt. on top of some of the above)	1.1 %	**12 %**	0.8 %	**6.1 %**	0.6 %	**4 %**
Charging at other activities (evt. on top of some of the above)	1.2 %		0.7 %		0.5 %	
The rest to fast charging	9 %		3.8 %		2 %	

The assumption for the calculation is that everybody will be able to charge at work if they need to. This might be an acceptable assumption for bigger firms. However, at small firms the option to set up a 16 amp pole might not be acceptable but a 10 amp socket might be found. Because of the long time staying at the job the difference between having a 10 and 16 amp socket will only change the result marginally. But if half of the population do not have access to any charging at all at the workplace the need for fast charging will increase from 3.8 % to 4.8 %. Charging at shopping and at the city centres will increase from 0.7 to 0.9 %.

An alternative assumption could be that drivers prefer to charge at shopping centres and only charge at work if they cannot get enough electricity at shopping centres. In this case 1.1 % will charge at shopping or in city centres and 2.0 % will still need to charge at work. The reduction in charging at work is small because many need the long stay at work to charge.

The possibility to charge at work is therefore crucial for persons who live far from their job. They will of course only purchase an EV if they have or can get an agreement with their employer about charging. It should be mentioned that the ChoosEV trial 'Test an EV' shows that people commuting long distances seem to be specially interested in an EV because they are saving much money pr kilometre because the EV is more cost effective than a conventional car.

A third alternative calculation is done to illustrate the impact of fast charging that will charge the battery up to 80 % in 20 minutes. It is in this calculation assumed that all charging poles with 3 pole 16 amp sockets are replaced by such a charging facility. The calculation reach to the surprising result that 17 % **less** will get enough electricity than in the case with the 3 pole sockets! If everybody that need a 3 pole charging pole charge using this and the rest will supplement with the fast charging facility up to 80 % the need for real fast charging will be reduced by 0.7 % or 0.03 percent points. This analyses shows that it from a practical point of view should be prioritised to install a 3 pole charger in the cars and not to base charging on a one pole DC charging facility. We will come back to the economic question in a later paragraph.

© Copyright EDISON Consortium. 2009. All Rights Reserved

Table 5-3 Number of trips with charging per 100,000 EVs at the different activities and in city centres. The number is shown at different capacities and depended on whether those who need to fast charge will charge when possible.

		No charging at charging poles for cars that need to fast charge			Full charging at charging poles for cars that need to fast charging		
	All travels	80 km	120 km	150 km	80 km	120 km	150 km
Home (not night charging)	129,000	7,300	3,500	2,000	11,100	4,900	2,900
Summer house	2,100	240	170	120	460	250	160
Work place	31,000	6,100	3,100	1,900	9,500	4,200	2,500
Education	1,500	270	150	70	440	190	90
Business travels and services	5,300	750	550	350	2,300	1,400	900
Town Centre in all	36,500	1,900	1,100	700	3,600	1,700	1,000
Shopping	30,900	1,600	700	400	3,500	1,400	900
Post offices, libraries, doctors etc,	3,300	130	30	10	430	130	70
Visiting friends and relatives	16,900	1,500	1,100	800	4,300	2,200	1,500
Sports activities	5,200	270	120	100	800	330	220
Entertainments	4,700	-	-	-	-	-	-
Private meetings	1,100	-	-	-	-	-	-
Other kind of club membership	2,200	140	70	50	340	160	100
Hospitals etc,	2,200	130	60	30	420	180	90
Escorting to activities	21,100	160	110	90	1,000	420	260
Escorting to Public transport	1,100	-	-	-	-	-	-
Collecting or delivering materials	5,700	-	-	-	-	-	-
Short trips	1,100	-	-	-	-	-	-
Weekends and holidays	1,700	-	-	-	-	-	-

Table 5-2 shows that the distribution of where to charge outside home is not quite the same at the three travel ranges 80, 120 and 150 km. The difference in distribution is assessed to be more a question about uncertainties because of a rather small number of persons and a big variation in travel behaviour of the cars. For instance only 700, 376 and 214 respondents respectively are assumed to charge at shopping centres or in the city centre and do not need to charge at visits or other activities.

Table 5-3 shows how many stops at different activities the EVs will do. The figure is shown in number of stops per 100,000 EVs in the car stock. In the three columns in the centre of the table the figures are shown if it is assumed that those who need to fast charge will not charge at normal poles too. In the columns to the right it is assumed that they will charge every time it is possible. The truth is of course between the two extremes, if the stop is short or the amperage is only 10 Amp it will make no sense to spend time on charging, but if the stop is longer or the amperage is higher the extra effect before the long trip will matter. The column furthest to the left shows how many stops are made at all per 100,000 vehicles. The biggest difference between the two set of columns with charging before fast charging and not is for the short travel range. However, the most important differences are between purposes.

What can be seen from Table 5-3 is first of all that even if all cars were electric only a smaller share will need to or want to charge in a certain place. The most frequent need will be at work places and education at which 10-14 % of the parked EVs will charge (the numbers are cited for a travel range at the medium level of 120 km). If only for instance 10 % of the car stock is electric then only 1-1.4 % of the parked cars will charge. For business trips the charging rate will be higher (10-26 % of the EVs) dependent on whether the user will charge before a long distance travel or not. This shows that firms which have many

© Copyright EDISON Consortium. 2009. All Rights Reserved

business guests or much service to be done ought to take these into consideration and plan for an extra charging pole for these. For all other activities the need for charging is very little so the need is more to have a charging pole available at certain places than setting up a row of poles.

Table 5-4 Share of parking lots that need charging facilities if all vehicles were electric, at a normal day (travel range 120 km and no charging before long distance travel) and an extreme day (travel range 80 km and everybody want to charge before a long distance travel)

	Normal day	Maximum need
Work place	10 %	31 %
Education	10 %	30 %
Business travels and services	10 %	42 %
Town Centres	3 %	10 %
Shopping	2 %	11 %
Post offices, libraries, doctors etc.	1 %	13 %
Hospitals etc.	3 %	19 %
Sports activities	2 %	15 %
Other kind of club membership	3 %	15 %
Escorting to activities	1 %	5 %
Visiting friends and relatives	6 %	25 %
Home (not night charging)	3%	10%
Summer house	8 %	22 %

Table 5-4 gives an overview of the maximum need for charging as a share of the parking vehicles if all cars were EVs. Two situations are illustrated, an average and thus typical day and a more extreme day with low temperatures or high speeds. Especially at working places it is necessary to take the worst case into account because the employees are at the parking lots at the same time of the day and they need to be able to get home even in winter when the travel range would be only 80 km and those who need to fast charge will want to charge at work too. In this case – taking the business visits into consideration too – 3-4 % of the parking lots need to be supplied with charging poles if 10 % of the car stock is electric and 15-20 % if it increases to 50 %. Universities will need the same share of charging poles to cover the students' cars.

In town centres and in shopping centres the need is only 5 % of the parking lots even in the extreme situation if 50 % of the car stock is EVs. At other recreational and social service facilities the charging need at a normal day is low. But if people will charge before a long home trip the number of car visits for charging is much higher. In practise it should not be expected that so many will try to charge at these places as it is difficult to get access to charging facilities at such places. We have only taken a normal 10 Amp plug into account which will only extend the travel distance at the battery very little by an extra hour of charging.

At private visits at friends and relatives a larger share will need to charge before going home but still it is only 6 % of the visits with all cars being electric. However in the extreme situation a larger share will need to ask their host for charging under a visit. [As the price for charging is less than 5 dkr per hour and a complete charging of a 16 kWh battery is 32 Dkr most hosts and visitors might find a solution for that.]

© Copyright EDISON Consortium. 2009. All Rights Reserved

Some – not many – EV owners will have the opportunity to charge at home in daytime or in their summer house. But for all EV owners the night charging is the most important. And if they have a summer house they will have to establish some kind of charging facility there too.

5.3 NEED FOR NIGHT CHARGING FACILITIES AT DIFFERENT GEOGRAPHICAL AREAS

To secure the possibility to make intelligent charging at night it is necessary to have a charging pole at home where the car can be charged. This is only possible for families living in single family houses where they can park.

Table 5-5 Number of needed parking lots with access to a charging pole for night charging in dense city areas if 100,000 families purchase an EV

	Town area		
	City centre	Dense area	Total
Copenhagen and Frederiksberg municipalities	242	4,151	4,393
3 cities >70,,000 inhabitants	229	1,256	1,484
Cities with 35-100,000 inhabitants	525	600	1,126
Cities with 20-35,000 inhabitants	634		634
Cities with 10-20,000 inhabitants	738		738
Cities with 5-10,000 inhabitants	641		641
Total	3,008	6,007	9,016

For families living in the central parts of the cities and in the rest of the dense city areas where the houses are built along the pavement it is not possible to park in private areas. Table 5-5 shows how many parking lots with charging facilities are needed in these areas of the bigger cities if 100,000 families purchase an EV (the EV frequency is expected to be the same everywhere). Close to the half is needed in the municipalities of Copenhagen and Frederiksberg and 1/6 in the 3 other big cities (Århus, Odense, and Aalborg). 1/3 can be spread out to the rest of the cities with more than 5,000 inhabitants. Some of these have access to parking spaces in parking cellars or in the backyards but in Denmark this is not an option for most of the flats and houses in the dense city areas in the 4 biggest cities. Therefore it is needed to establish charging poles along the streets. In the smaller cities it is more common to have access to semi private areas in back yards so in these cities less charging poles are needed in the streets. In all 7,500 – 8,000 charging points are needed. Most of these can be established as charging poles with two plugs. The conclusion is that in all around 4,000 charging poles are needed in public residential areas if 100,000 families will purchase a passenger EV. Half of these have to be located in Copenhagen and Frederiksberg. To this figure has to be added the need for charging facilities for vans which we do not know so much about at the moment.

In the dense areas access is also needed for charging facilities in the streets for charging at work. Table 5-6 shows how many EVs will need to charge at work in the city centres and other dense areas if 100,000 families have an EV and the EV frequency is expected to be the same everywhere. The travel range is assumed to be 120 km in the calculations. In Copenhagen only 314 EVs need to have access to a charging pole at work. This means that it is not needed to establish extra charging poles for charging at work because these EVs will easily be able to use charging poles which are getting free when the residents leave in the morning for work and other activities.

© Copyright EDISON Consortium. 2009. All Rights Reserved

Table 5-6 Number of needed parking lots with access to a charging poles for charging at work and at other purposes in dense city areas if 100,000 families purchase an EV and the practical charging range is 120 km (EVs are expected to charge even if they need to fast charge later).

	For work		For other purpose (non-home)		
	City centre	Dense area	City centre	Dense area	Total
Copenhagen and Frederiksberg municipalities	45	269	59	281	654
3 cities >70,000 inhabitants	52	103	129	120	404
Cities with 35-100,000 inhabitants	121	41	303	61	525
Cities with 20-35,000 inhabitants	76		166		242
Cities with 10-20,000 inhabitants	66		228		294
Cities with 5-10,000 inhabitants	93		195		287
Total	453	413	1,079	463	2,407

The same is the case for other activities in the city centres and other dense areas. But some of the medium size cities are getting many visits in the city centres by EVs. They will have close to as many visiting EVs that need to charge as residents leaving. However, most of the visits are short and more than one visit can come to each charging spot over the day time. The biggest problem can be the evening visits when both residents and visitors will try to use a charging spot at the same time. For this reason a little extra charging capacity can be needed for the evenings.

Table 5-7 Number of towns under 5,000 inhabitants and areas outside the city centres in the bigger cities and towns that need charging facilities for shopping activities etc.

	Charging poles in other centre areas		
	Number of areas /cities	Charging poles pr area/city	Overall in non-city-centre areas
Copenhagen region			
Rest of Copenhagen and Frederiksberg	12	2	24
Suburbs	17	2.5	43
Cities > 100,000 inhabitants	3	5	15
Cities 40-100,000 inhabitants	11	5	55
Cities 20-40,000 inhabitants	17	4	68
Cities 10-20,000 inhabitants	32	3	96
Cities 5-10,000 inhabitants	51	2	102
Cities 2-5,000 inhabitants	185	1	185
Big shopping centres and Megastores	60	3	180
In all			780

Outside the dense city area and city centres most need for charging outside private and semi private areas will be for shopping Table 5-3 show that 700-1400 EVs per 100,000 EVs need to charge at shopping in small towns and outside the city centres. Many of these stops will be short but of course more than 13 minutes because else they were not included in the calculations. This means that each charging pole can be used several times in the running of the day. But of course at rush-hour on Saturdays the need will be bigger in line with more need for parking spaces. Table 5-7 is a very rough estimate indicating where we expect charging poles to be needed. It is first of all in the big shopping centres and mega stores. But it is also in typical suburb shopping centres of the bigger cities. The table is mentioning the number of cities in each size. And the number of places in suburbs is higher the larger the city is. Town centres of smaller towns which are not included in Table 5-6 are taken

© Copyright EDISON Consortium. 2009. All Rights Reserved

care of in the table. The suggested 780 charging poles or 1000 to be on the safe side should be enough for the first 100-200,000 EVs as each pole can be used by two cars. What is most important is to get them spread out in the suburbs of the cities.

The conclusion must be that no more than 5,000 charging poles are needed in public areas for the first 100,000 EVs. The need will increase by 4,000-4,500 each time the number of EVs will increase by 100,000.

5.4 FEASIBILITY OF INVESTMENTS IN CHARGING POLES

As the system is assumed to be built up in the calculations only charging poles in the city centres and at shopping centres are expected to be set up by a body independent of the EV driver. Charging at work places should be an agreement between employees and employers at least in the beginning and as mentioned above charging at other facilities are expected to be a 10 Amp sockets which can be found somewhere at the activity.

The relevant question is therefore if investments in public accessible charging poles in city centres and at shopping centres are an efficient investment and when.

We expect a private installed charger at their private address with smart grid to cost 10,000 kr and a charger in public to cost 50,000 kr. An EV customer living in the dense city areas who need to charge at a public space is expected to pay at least 10,000 kr for this public service as his colleagues in their private houses or in areas with apartments in private and semi private areas have to pay for their. If the investment of 10,000 is financed over 10 years with an interest rate of 7 % the EV owner has to pay 116.11 kr a month and 198.01 kr if the loan has to be paid back over 5 years.

The pole can as mentioned be used by two EVs which pay 10,000 kr each. So the investors still need an income of 30,000 per pole for 4,000 poles in the dense city areas and 50,000 kr for 500-1,000 poles in other areas if the EV stock is 100,000 vehicles.

According to Table 5-6 the 4,000 poles in the city centres and other dense areas will be visited 2,000 times per day on average on top of the night charging, and according to Table 5-7 the rest of the poles will be visited 700-1,400 times.

In Table 5-8 is shown how such an investment could be financed if all vehicles are available from the beginning. It is assumed that the investors will accept the investment to be depreciated over 10 years with an interest rate of 7 %. With an investment of 170 mio kr the monthly yield over 10 year will be a little less than 2 mio. kr.

Table 5-8 An example of how an investment in charging poles for 100,000 EVs could be financed

	Investment			Interest rate	Number of setting	Yield over 10 years	Visits per month	Mean payment
	Number of poles	Per pole	In all		months			pr visit
City centres	4,000	30,000	120,000,000	7%	120	1,393,302	72,000	19.35
Other areas	1,000	50,000	50,000,000	7%	120	580,542	21,000	27.64
In all			170,000,000			1,973,844	93,000	21.22

With the stipulated number of customers per day according to Table 5-6 the needed payment per visit according to Table 5-8 should be a bit more than 20 kr per visit (21.22 kr per day) or 3 EUR. For a customer who only needs to charge occasionally in the city centres 20 kr for a full charge on top of the normal payment for the electricity might be an acceptable level. However for the daily or frequent visitor, e.g. commuters it might be too much. Instead you could set up a system where the frequent visitor has a subscription and the occasional customer pays per visit.

© Copyright EDISON Consortium. 2009. All Rights Reserved

Table 5-9 Illustration of possible income if 10 % of the charging visitors are subscribers with a monthly payment of 60 kr and 90 % pay 20 kr per charging visit

	Visits	Customers	Per month / visit Kr	Income per month
Subscriptions	23,250	10,000	60	600,000
Visitors	69,750	90,000	20	1,395,000
In all	93,000	100,000		1,995,000

According to Figure 4-2 10 % of the EV owners with 1 car and 2 driving licences will need to charge outside home more than 3 days in a fortnight period, about 5 days in average. 90 % will charge 0 - 3 days or 1.5 days in average over the fortnight period. Families with 2 cars are driving around the same number of kilometres per day and have the same need for charging outside home as those with one car and two licences. So for the calculations we can assume that 90 % of these to charge 1.5 days each too. According to Figure 4-1 the single EV owners will only charge 1.2 days per fortnight. It is not possible to use these figures as an absolute number of visits because they include charging at many other sites than in the dense city areas and other public shopping areas etc. In fact they make up around 4 times as many visits as the 93,000 we find in Table 5-8. Instead they can be used for a distribution between the 10 % who charge often and the 90 % who charge occasionally.

In Table 5-9 it is assumed that the subscriptions will make up ¼ of the charging visits and the payers per visit will represent ¾ of the visits. With a subscribtion price of 60 kr per month and payment of 20 kr per time of the occasional charging visitors Table 5-9 shows that the income (1.995 mio kr per month) will be what is needed according to Table 5-8 (1.974 mio). If the occasional visitors demand a little less then the monthly payment has to be increased to 65 kr. The relation between the monthly rate and the single time fee also seem to be acceptable because the 10 %, who are expected to subscribe for 60 kr are charging more than 3 times as often as the rest.

In these feasibility calculations it is assumed that there are 100,000 customers for 5,000 charging poles. But in the beginning some charging poles have to be established for the customers to come. All the 5,000 charging poles are not needed from the beginning because 4,000 of these are based on the necessity to cover the demand from the residents in the city centres if they should have the same frequency of EVs as inhabitants in other areas. But the first say 2,000 poles are needed to cover the central area and give an impression that it is possible to get access to charging facilities if you buy an EV. These 2,000 charging poles spread out in the cities and at shopping centres will not be feasible if the investor's only interest is to earn money on setting up charging poles. But after this initial investment, which might be financed of those who want to be in the EV market, it will be an acceptable business to set up charging poles if the customers are charged in a way as described here: 20 kr per charge for single use customers, 60 kr per month for subscribers to get general access to charging poles in all public areas and 120 kr per month for those who needs to charge at home. If they wish to charge outside their home area in day time, they will need to have a subscription for this too. This results in a general subscription fee of 180 kr per month.

In the above calculations a 3 phase 16 amp charging pole is expected in the city centres and shopping areas. In the dense areas a 1 phase charging pole will be acceptable. However, if 3 phases charging is impossible to be used by the EVs, 50 kW DC chargers will be needed instead in a high share of the 1,079 charging poles in the city centres for 'other purpose' according to Table 5-6 and the 780 in other centre areas according to Table 5-7. The price of these is at the moment 5 times as high as for the 3 phase charging poles. And the customers will be less, because it will not be possible to use them both for the residence and for the day visitors because the residents can do with a one phase charging pole and will not be allowed to stand a whole night at a 50 kW DC charger. In this case the investment cannot be financed and the government has to invest instead if it wants EVs on the market immediately.

© Copyright EDISON Consortium. 2009. All Rights Reserved

But what is the economic logic behind this situation? According to an interview with Daimler (Foosnæs, 2011a and Daimler, 2010) a charger for 1 phase costs 300 $ and for 3 phase costs 800 $. The extra 500 $ (1,500 kr) have to be financed by the automotive industry as long as the price of an EV is a market price and not a production price. In the long run the price will be closer to the production price and the extra price for the charger has to be paid by the customer. For 100,000 cars the extra price will be 150 mio kr. This will save an extra investment in about 2,000 poles or 400 mio kr. on top of 100 mio kr for the cheaper 3 phase poles with lower effect.

To conclude the 3 phase charging poles combined with the needed charger is the practical best solution and also the cheapest. The only question is who will decide: *the manufactures*; and who will gain in the short run: *the manufactures*. However, competition will help to the best long term solution.

© Copyright EDISON Consortium. 2009. All Rights Reserved

6 LOCATION OF FAST CHARGING FACILITIES

In chapter 4 is analysed if the EV owner needs to charge at charging poles for a smaller power addition during the day. However, according to Table 5-2 between 2 % and 9 %, depending on the travel range, will need to fast charge. This means that they cannot do with charging when they are at an activity; they will in addition need to stop on a trip with the only purpose to charge. In this situation most will want to charge as fast as possible. In this chapter is discussed the need for fast charging more in details and a model to optimize the localisation is presented.

6.1 NEED FOR FAST CHARGING

Sometimes the car owner will travel longer distances and therefore needs to fast charge during the trip. According to the analyses in chapter 2, 9 % will fast charge at the actual day depending on the travel range. However, seen over a longer period a larger share of EVs will need fast charging. Less than half of the drivers can avoid fast charging during a month if their car has a driving range of 80 km, cf. Figure 6-1. If the range however is 150 km it is more than two thirds that can avoid fast charging during a month. If the travel range in practise is 120 km 60 % can avoid fast charging. Less than 80 % needs to fast charge once and 95 % needs to fast charge at maximum one day a week in average.

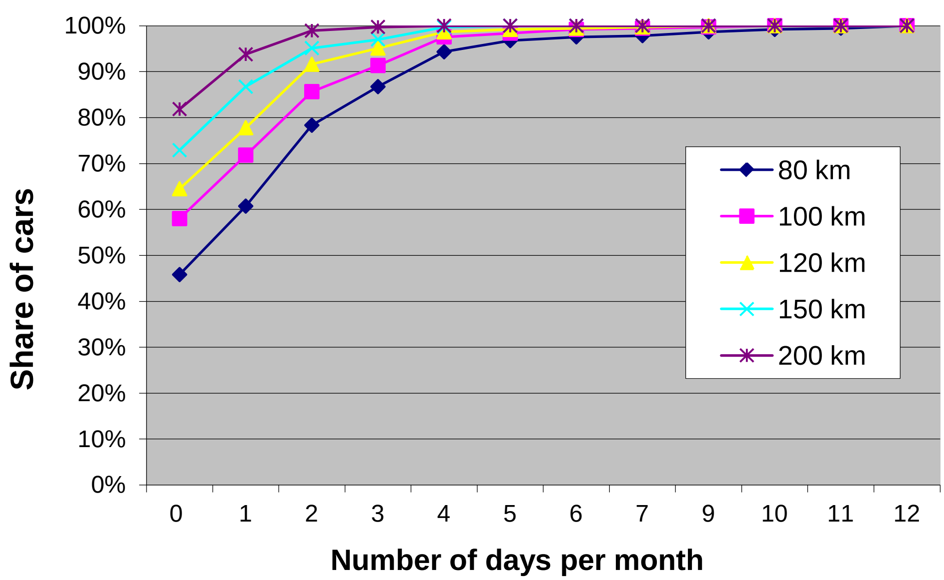


Figure 6-1 Share of cars that needs to perform fast charging at maximum 1, 2 3 ... times within a month. AKTA data

Table 6-1 Average number of fast charging operations per day for EVs that need to charge the actual day. AKTA data

Travel range:	**80 km**	**100 km**	**120 km**	**150 km**	**200 km**
One car families with 1 car and 2 driving licences	1.82	1.70	1.54	1.38	1.26

Furthermore it will often be necessary to charge two or several times during the day, once the need for fast charging has been established (Table 6-1). If the capacity is 80 km, it is less than 50 % of the cars that can do with charging only once, and 20 %

© Copyright EDISON Consortium. 2009. All Rights Reserved

must charge more than 3 times. And even in case of a capacity of 150 km, half of the cars must charge more than once the actual day. One of the reasons for this is of course that many of the long distance travels consist of an outbound and a return trip which are both too long for driving them in one charging.

6.2 LOCATION OF FAST CHARGING FACILITIES

As part of the Edison project a methodology to optimise localisation of fast charging stations is developed. The analyses are based on origins and destinations of all trips over the day of cars that need to fast charge one or more times along the interview day. It is presupposed that the charging stations are located at some of the existing gas stations of which exists around 1,800 today. The method is split into three stages (Figure 6-2).

Stage 1 reads the TU data and a digital map of Denmark, which includes the entire road network and builds the digital search graph. Origin and destination pairs of the TU data are used to find the extended routes for all trips based using a fastest route algorithm. Kilometres for all cars are used in the simulation part to calculate the fast charge potential points in the road network, which is the node of the network closest to the point where the maximum travel range minus the 20 km safety margin is located. The extended trips and fast charge potential points are stored as output of stage 1.

Stage 2 reads the data for the existing gas stations and includes the fast charge potential points from stage 1 to find the optimal location of fast charging stations. Then the location model uses simulated annealing to find which gas stations that should be upgraded to serve EVs. The list of upgraded gas stations and the matching between gas stations and fast charge potentials are stored as output from stage 2.

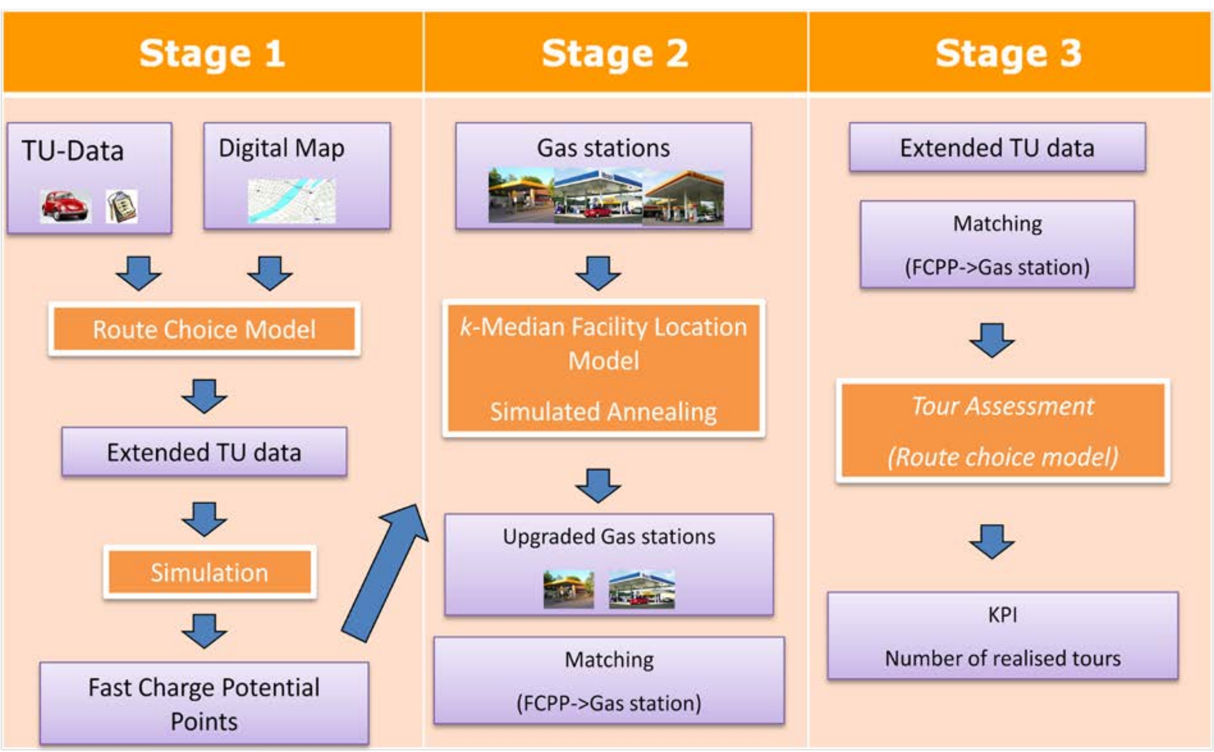


Figure 6-2 Illustration of the principles of the calculation of the optimizing of the localisation of the fast charging stations (TU data is the Danish name for the NTS data)

© Copyright EDISON Consortium. 2009. All Rights Reserved

Stage 3 reads TU data, fast charge points, Gas stations and extended trips. These data are used in a simulation where the number of customers, which can be served by an upgraded gas station, is calculated for all extended trips. If the stations cannot be reached by the fastest route, the shortest route is used instead.

The list of the customers is stores with information on which cannot be served and how long and time consuming the detour is is stored as output from stage 3. Furthermore a list of guests at each fast charging station is found too.

The model is described in details in Appendix 1. For the theory refer to Laporte et al (2011) and Madsen (2010).

Figure 6-4 shows 4 examples of optimal localisation of fast charging stations depending on the number of stations using the developed optimisation model. It is clear that the fast charging points calculated from the trips follow the motorways from Copenhagen across Fyn and to the north and south in Eastern Jutland. The fast charging stations are following these motorways too with few stations. Not until about 50 stations are established will the whole country be covered. Greater Copenhagen is not getting any fast charging station until 20 stations is established. The first and most important station is the one to the south of Copenhagen where the motorways to the west and to the south are splitting out.

Figure 6-3 is showing the detours and the share of trips that cannot be fast charged. The analyses is based on 1,440 trips which gives an average detour of 2 km with 100 stations and 3 % of the tours which cannot be served..

Since these calculations were made the model has been improved as part of the Ten-T project, Greening European transportation infrastructure for electric vehicles. The new analyses appear to indicate a need for less stations. However, the calculations are not finished yet (Christensen et. al., 2011).

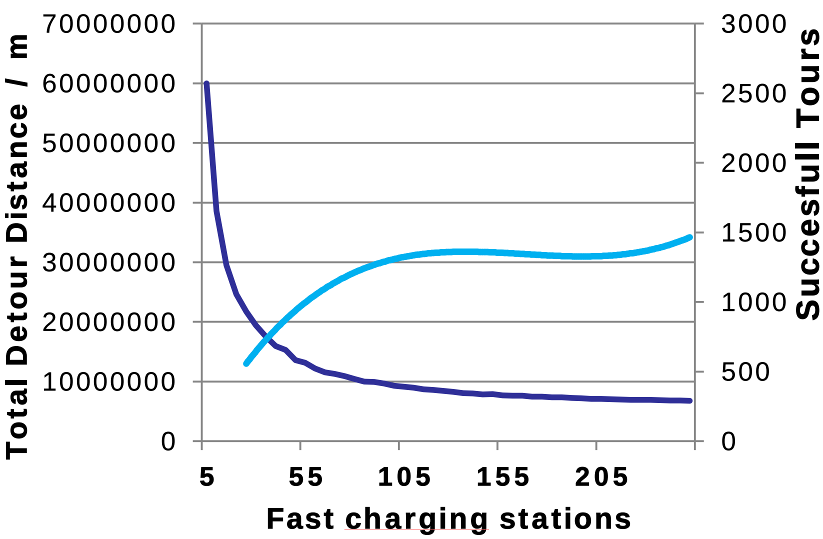


Figure 6-3 Total detour in meter depending of the number of fast charging stations, dark blue curve. The number of tours which gets fast charging (1441 tours in all), light blue curve.

© Copyright EDISON Consortium. 2009. All Rights Reserved

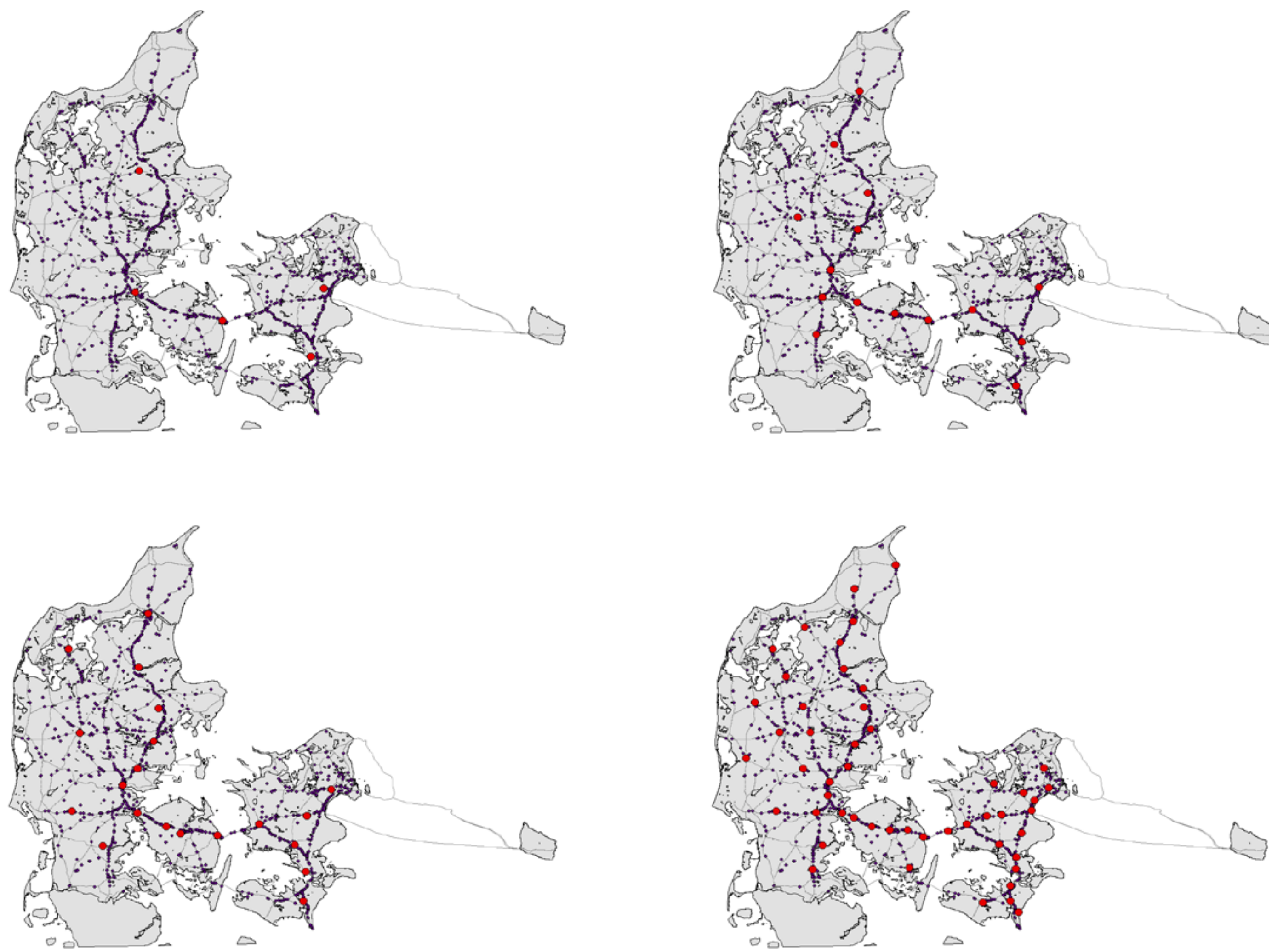


Figure 6-4 Localisation of 5,15, 20 and 50 fast charging stations calculated by the model. The black spots shows the Fast Charge potential Points from the trips

© Copyright EDISON Consortium. 2009. All Rights Reserved

7 REFERENCES

AKTA data (2001-2003): *Unpublished raw data on The AKTA Road Pricing Experiment in Copenhagen.*. Technical University of Copenhagen, Denmark.

Transportvaneundersøgelsen (2011): *Unpublished raw data of The Danish National Travel Survey*. http://www.dtu.dk/centre/Modelcenter/TU.aspx

Axhausen, K.W.(2007) *Travel Behavior Research*: Proceedings of Iatbr 2003. Amsterdam: Elsevier.

Axhausen K. W., S. Schönfelder, J. Wolf, M. Oliveira, U. Samaga (2003): *80 weeks of GPS-traces: Approaches to enriching the trip information.* Submitted to the 83rd Transportation Research Board meeting, August.

Better Place, 2011: http://danmark.betterplace.com/faq/bilen/

ChoosEV, 2011: http://www.choosev.com/viden-om/koersel-i-elbil (travel range),
http://www.choosev.com/viden-om/elbilen (car performance)

Christensen, L., S. Kaplan, T.C. Jensen (2011): *The need for charging infrastructure for a large market share of electric vehicles* Under preparation

Christensen, Linda, Fosgerau, Mogens (2002): "*Impacts from different land-use strategies on travel distances*". AET conference 9. - 11. Septembre 2002. Cambridge, Great Britain, Conference CD.

Christensen, L. (2000): *ALTRANS. Transportvaner og kollektiv trafikforsyning*. Afdeling for Systemanalyse. 154 sider. Faglig Rapport fra DMU nr. 320.

Christensen, L. (1994): *Udviklingen i transportvaner 1975-1993*. I: Lahrmann, H. & Pedersen, L.H. (red.): Trafikdage på AUC, 29.-30. August 1994. Transportrådet og Aalborg Universitet. Trafikforskningsgruppen. - Supplementsrapport s. 135-145.

Daimler (2010): http://www.eurelectric.org/Highlights/20110505EV/index.html

Foosnæs (2011a): Report: wp1.2 *Interview with Daimler HQ*

Foosnæs (2011b): Report: wp1.2 *Interview with Renault HQ*

Foosnæs (2011c): Report: wp1.2 *Interview med Renault*

Foosnæs (2011d): Report: wp1.2 *Interview with Peugeot HQ*

Foosnæs (2010): Report: wp1.1 *Electric vehicle technology*

Hacker, F., Harthan, R., Matthes, F., Zimmer, w. (2009). *Environmental impacts and impact on the electricity market of a large scale introduction of electric cars in Europe - Critical Review of Literature*. ETC/ACC Technical Paper 2009/4 July 2009. European Topic Centre on Air and Climate Change (ETC/ACC). URL: http://acm.eionet.europa.eu/docs/ETCACC_TP_2009_4_electromobility.pdf

Hjorthol, R. & Næss-Kjørstad,K.(2006) *Gender equality in transport* , TØI report 866/2006,Norway Kjærulff (2011):

Laporte, G., O. B. G. Madset, A. V. Nørrelund, A. Olsen, M. Wen (2011): *Locating of Replenishment Stations for Electric Vehicles*. Submitted for ?.

Madsen, O.B.G. (2010): *Location of Electric Replenishment Stations for Electric Vehicle.* Network Optimization Workshop 2010, August 22-25, 2010 Ajaccio, Corsica

Nielsen, O. A., M. V. Sørensen (2008). *Road Pricing, the Economy and the Environment*, chapter The AKTA Road Pricing Experiment in Copenhagen, pages 93–109. Advances in Spatial Science. Springer Berlin Heidelberg.

© Copyright EDISON Consortium. 2009. All Rights Reserved

Nielsen, O. A. C. Würtz (2005): *Using GPS for road pricing: Experiences from Copenhagen. In Proceedings 19th World Congress and Exhibition on Intelligent Transport Systems and Services*, number Session: PS 117, 2003. Presented at: 19th World Congress and Exhibition on Intelligent Transport Systems and Services : Madrid, Spain.

Nielsen, O. A. (2002). T*he AKTA road pricing experiment in Copenhagen*. In Proceedings of the European Transport Conference, Strasbourg, France.

Nissan, 2011: http://www.nissan.dk/#vehicles/electricvehicles/leaf/car-of-the-year

Pearre, N. S., W. Kempton, R. L. Guensler, V.V. Elango (2011): *Electric vehicles: How much range is required for a day's driving?* Transportation Research Part C. Page 1171-1184.

Polk, M. (2004). Gender Mainstreaming in Transport Policy in Sweden, *Kvinder, Køn og Forskning, nr. 2004, Københavns Universitet 2004*

Renault, 2011: http://www.renault-ze.com/da-dk/z.e.-serien/kangoo-z.e./prasentation-524.html

Schönfelder, S., K.W. Axhausen (2010): *Urban Rhythms and Travel Behaviour: Spatial and Temporal Phenomena of Daily Travel.* Farnham, England: Ashgate.

Stopher, P., Y. Zhang (2011): *Is Travel Behaviour Repetitive from Day to Day?* Transportation Research Board, Washington, DC. January

Stopher, P., C. Prasad, Y. Zhang (2010): *Comparing GPS and prompted recall data records.* 12th World Conference on Transport Research, July 11.-15. In Lisbon, Portugal

Stopher, P., C. FitzGerald, T. Bretin and J. Zhang (2007). Analysis of a 28-Day GPS Panel Survey – Findings on Variability of Travel, *Transportation Research Record No. 2014,* Transportation Research Board, Washington, DC., pp. 17-26.

Ten-T (2011): *Greening European transportation infrastructure for electric vehicles*: http://energymap.dk/Cache/f0/f04cecd7-27ae-4714-955b-4451812b2a45.pdf

Tesla (2011): http://www.teslamotors.com/roadster/specs (Tesla Roadster specification)
http://www.teslamotors.com/goelectric/efficiency (energieffektivitet)

Think (2011): http://www.think.no/nor/THINK-City

© Copyright EDISON Consortium. 2009. All Rights Reserved

8 APPENDIX 1 EDISON LOCATION UTILITY

By Allan Olsen and Anders Vedsted Nørrelund

8.1 STAGE 1 PREPROCESSING/SIMULATION

The extended TU-Trips are calculated in the preprocessing phase which is based on a state of the art shortest path algorithm which uses a route choice model to calculate the shortest path for each trip in the TU Data. The route choice model uses 3 parameters which are derived from Danish studies on route choice models.

- Cross Preference 0,1
- Distance Preference 0,77
- Time Preference 1,621663

The model uses a linearized objective which is used to find the shortest path in the road network.

- Cost of travelling = crosspref * NoOfJunctions passed
  + distpref * Km travelled
  + timepref * Minutes travelled

This objective is a simplified version of the full model. The running time of the simplified version is 1 hour compared to 3 days for the full model.

The cross preference indicates the cost of travelling through a junction in the road network. The distance preference indicates the cost of travelling 1 km in the network. The time preference indicates the cost of travelling 1 minute in the network. The maximum allowed speed on each link is used to calculate the travel time.

The cost of travelling 1 km at 60 km/h going through 10 junctions in a car: = 0,1 * 10 junctions + 0,77 * 1 km + 1,621663 * 1 min = **3,39**

The chosen parameters will tend to choose paths from origin to destination were the car chooses bigger roads with higher possible speeds and fewer junctions.

After the preprocessing phase simulation is used to identify the Fast Charge Potential Points for all TU trips. In order to find the potential fast charge points the following parameters are introduced.

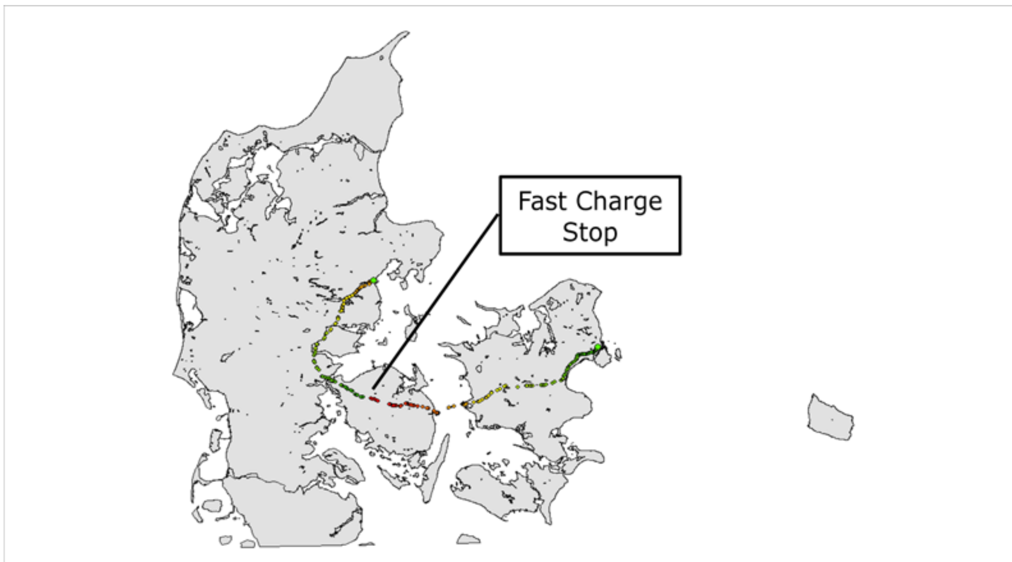
Parameter	Value	Description
ChargeRate	0.4 km/min	The charging rate for home charging
ChargeDiscrepancyMin	15 min	The time between 2 trips must exceed this time interval in order to start home-charging
SafetyBufferKm	20 km	Defines when the driver searches for tanking options
FastChargePercentage	100 %	What capacity do we have in the car after a fast-charge

© Copyright EDISON Consortium. 2009. All Rights Reserved

The simulation is simply based on the assumption that the car is fully charged when departing from origin and then gets discharged the further it goes. When the car reaches its safety buffer a fast charge potential point is stored in the model. This procedure continues until the car reaches its destination. If the car stops during the trip it can use “home” charging if the stop exceeds 15 min. At all fast charge potential points and ”home” charging points the car is able to charge to 100% which is the fast charge percentage.

The picture below depicts a trip from Copenhagen to Aarhus where the simulation finds the fast charge stop potential point in the western part of Funen. As the car discharges during the drive from Copenhagen the path/battery level changes color from green to red. When the car is fast charged the battery is fully charged again, and the car can continue the trip to Aarhus.

Stage 1 stores all fast charge potentials which are used in stage 2.



8.2 STAGE 2 K-MEDIAN FACILITY LOCATION MODEL

As mentioned above stage 2 uses the fast charge potentials calculated by the preprocessing and simulation algorithm in stage 1. Furthermore stage 2 reads the data for the existing Gas stations in DK and uses these data as input for the Facility Location Model.

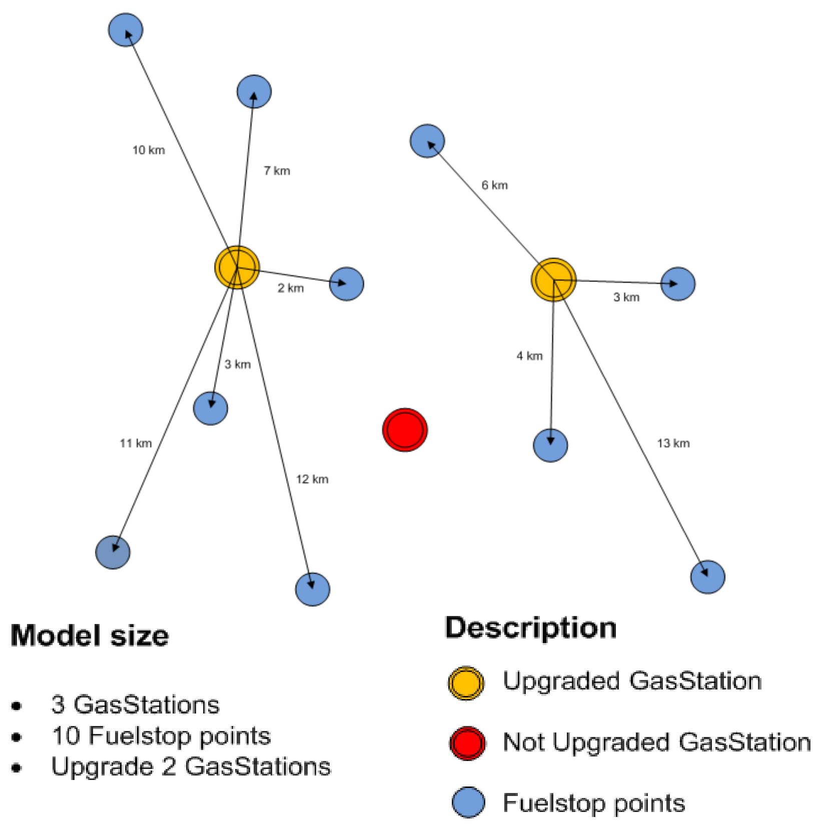
The k-Median Facility Location Model:

© Copyright EDISON Consortium. 2009. All Rights Reserved

Minimize	$\sum_{i \in D} \sum_{j \in S} d_{ij} \cdot x_{ij}$		(1)
Subject to			
	$x_{ij} \le y_j$	$\forall i \in D, j \in S$	(2)
	$\sum_{j \in S} x_{ij} = 1$	$\forall i \in D$	(3)
	$\sum_{j \in S} y_j = K$		(4)
where	$x_{ij} \in \{0,1\}$, $y_j \in \{0,1\}$		(5)(6)

(1) Minimize the total distance of each demand point i to station j
(2) The demand point i can be served by station j if and only if station j is opened.
(3) Each demand point can be served by exactly one fuel station.
(4) There are K stations open
(5) x_{ij} are binary decision variables, it is 1 if demand point i is served by station j
(6) y_j are binary decision variables, it equal to 1 if fuel station j is open.

Example:



Each trip is served by the closest open gas station in euclidean distance

© Copyright EDISON Consortium. 2009. All Rights Reserved

The objective of the optimization is to find the combination of open gas stations, which minimizes the objective

Objective Function: The sum of all tours distance to the closest gas station

In the 10+7+2+11+3+12+6+3+4+13=71 km is found

SIMULATED ANNEALING

The model is solved by the Meta heuristic – Simulated Annealing (SA) which uses 1-opt and k-opt as optimization operators to find the optimal placement of fast charge stations.

SA is used when an optimal solution is impossible to find due to the problem complexity. SA is a good alternative which will find a near optimal solution to the problem by examining random variation of the current solution. A worse solution is accepted as the new solution with a probability that decreases as the temperature is cooling. The slower the cooling schedule, the more likely the algorithm is to find an optimal or near optimal solution.

The framework of the SA Algorithm is quite simple. Consider the pseudo code presented below.

The initial solution is constructed by selecting a certain number (K) of fuel stations to be opened. The SA algorithm seeks to improve the result by picking a random solution. Therefore, based on the original solution, a new solution is generated by randomly exchanging X opened station(s) with the closed stations.

Simulated Annealing Algorithm

1. $s \leftarrow$ Initial Solution (random generate K opened fuel stations)
2. Repeat
3. Loop L times
4. $s^* =$ n-opt / k-opt “move”
5. $\Delta = f(s^*) - f(s)$
6. if $\Delta \leq 0$, $s \leftarrow s^*$
7. if $\Delta > 0$, $s \leftarrow s^*$ with prob. $e^{-\Delta/T}$
8. $T \leftarrow T \times fc$ (fccooling factor)

Until stopping criterion

Return best solution found

8.2.1 1-OPT / K-OPT

Firstly, consider the function at line 4 in Algorithm 2. It reads the original solution and output a new solution. We call it the solution of a “move” in the SA procedure. The way of obtaining a new solution “s” is shown below in algorithm 3.

1-opt / k-opt (Move)

© Copyright EDISON Consortium. 2009. All Rights Reserved

1. For the current solution s

Random select X opened station(s)

Random select X closed station(s)

Exchange them

2. s* ← the solution after exchange

X could be any integer between [1, X]. However, in general, SA seeks to improve the result by doing a small change to the current accepted solution.

8.2.2 TEMPERATURE (T)

The temperature has several functions in SA procedure. It can help to define the stopping criterion or most importantly, it is used to determine the current probability of accepting worse solution. When temperature is high, the probability which is equal to $e^{-\Delta/T}$ is close to 1, meaning that the worse solution is easily accepted in current temperature. On the contrary, if the T value is rather low, the probability to accept worse solutions gets very low at the same time. Additionally, when using temperature as stopping criterion, normally, a starting temperature and ending temperature needs to be defined. And the procedure could also be stopped by other methods such as a maximum of running time without improvement of the current best solution.

8.2.3 COOLING FACTOR FC

The cooling factor is used to decrease the temperature after each iteration. If the cooling factor is close to 0, the temperature drops very fast which leads to a low accept ratio of worse solutions. On the contrary, a cooling factor close to 1, normally gives a better chance for the algorithm to accept a worse solution.

8.2.4 STOPPING CRITERION

The stopping criterion is set to a certain number of iterations.

8.2.5 SIMULATED ANNEALING – PARAMETERS

Parameters for the simulated annealing algorithm are listed below.

- T-start
- Num Iterations
- Cooling factor alpha
- Repeat factor

© Copyright EDISON Consortium. 2009. All Rights Reserved

8.3 STAGE 3

Stage 3 reads TU data, fast charge points, Existing Gas stations and extended trips. These data are used in a simulation where the number of customers which can be served by an upgraded gas station is calculated for all extended trips.

This procedure is done in order to compare KPI's for the different solutions calculated in stage 2. Stage 3 will yield a good measure on the number of fast charge stations needed to serve a certain percentage of customers in the localized area.

Furthermore the number of successful trips and detour distance is evaluated.

A brief overview of the Tour assessment algorithm is described below.

Tour Assessment Algorithm

1. Repeat (for all extended trips in a Daily schedule)
2. Foreach OD pair in one trip.
3. Loop L times
4. if (destination is reached)

   Go to next extended trip.
5. else

   Look for the destination or a possible fast charge station

   Find the path to the destination or the station

   Repeat step 4.

Until all extended tours has been evaluated

Return the number of successful tours

It is important to notice that the procedure is done for all extended trips from the TU data set. An increasing amount of located fast charge stations will yield an increasing number of travelers which can reach their end destination.

The algorithm uses the same route choice model as described in Stage 1. The objective function is extended with the time spend at each fast charge station stop.

- Cross Preference 0,1
- Distance Preference 0,77
- Time Preference 1,621663
- Fast charge factor 15

The model still uses a linearized objective which is used to find the shortest path in the road network.

- Cost of travelling = crosspref * NoOfJunctions passed

+ distpref * Km travelled
+ timepref * Minutes travelled
+ Fast Ch

© Copyright EDISON Consortium. 2009. All Rights Reserved